Effects of Headache on Clinical Measures of Neuropsychological Function and Postural Stability

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ABSTRACT

JOHNA KAY REGISTER: Effects of Headache on Clinical Measures of Neuropsychological Function and Postural Stability
(Under the direction of Kevin M. Guskiewicz)

Our purpose was to compare the recovery patterns of athletes reporting headache at baseline (PAH) and athletes reporting posttraumatic headache (PTH) following concussion. The study involved two separate analyses of concussed high school and collegiate athletes classified based on baseline headache scores and another by headache scores at twenty-four hours post-injury. All subjects completed a graded symptom checklist. A subset of subjects completed the Standardized Assessment of Concussion (SAC) and the Balance Error Scoring System (BESS) at baseline and days one, three, and seven post-injury. A smaller subset completed ANAM at a sub-acute session (1-2 days post-injury) and a prolonged session (5-7 days post-injury). Significant differences in symptomatology and mental status ($p<.05$) were observed for PAH and PTH. Differences were also observed in balance and neuropsychological performance scores regarding PTH. ($p<.05$) Results suggest that headache scores (PAH and PTH) should be considered in the interpretation of clinical measures of concussion.

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LIST OF ABBREVIATIONS

1. ANAM- automated neuropsychological assessment metrics
2. BESS- balance error scoring system
3. CDHA- chronic daily headache
4. CPT- continuous performance
5. GSC- graded symptom checklist
6. HA- headache
7. LOC- loss of consciousness
8. MHI- mild head injury
9. MSP- match to sample
10. MTBI- mild traumatic brain injury
11. MTH- math processing
12. PAH- pre-season assessment headache
13. PTA- post-traumatic amnesia
14. PTH- post-traumatic headache
15. RTP- return to play
16. SAC- standardized assessment of concussion
17. SRT- simple reaction time
18. STN- sternberg memory search
19. TTH- tension type headache

CHAPTER I

INTRODUCTION

Concussion is a common injury occurring in sport, as there are approximately 300,000 reported sports-related head injuries each year in the US. (Thurman, Branche, & Sniezek, 1998) Management of head injury and return to play (RTP) decisions have become debated topics in the healthcare community due to variability of management strategies and RTP guidelines. Although there is debate, most clinicians agree that assessment and management of concussion involves thorough and repeated evaluations. Concussion may result in a cluster of symptoms ranging from mild headache to loss of consciousness (LOC). Headache (HA) is one of the hallmark symptoms of concussion and occurs in up to 86% of concussed individuals. Many times, LOC and post-traumatic amnesia (PTA) are used as indicators of presence of concussion as well as concussion severity; however, LOC occurs in only 9% of cases and PTA occurs in only 23%. (Guskiewicz, Weaver, Padua, & Garrett, 2000) Despite being the most common concussive symptom, post-traumatic headache (PTH) is often over looked or dismissed as a minor symptom and there is a limited understanding about the relevance of this symptom specifically related to RTP. Current literature reports various effects of PTH on neuropsychological test scores and prevalence of symptoms. Collins et al 2003, reported increased deficits in neuropsychological test performance and increased symptoms in individuals suffering from PTH through 10 days post-injury. These individuals also demonstrated more on-field markers of concussion severity than individuals who did not suffer from PTH.(Collins et al., 2003) The presence of post-traumatic migraine (PTM) characteristics and PTH may also affect other symptoms and neuropsychological test scores. Individuals suffering from PTH with PTM characteristics suffered greater neurocognitive deficits and increased symptoms scores compared to a PTH group without those features and when compared to a non-HA group. The individuals reporting PTH also performed significantly worse on neuropsycholgical tests and reported an increased number of symptoms post injury compared to individuals reporting no-HA. (Mihalik et al., 2005) These studies indicate important effects of PTH on clinical measures of concussion; however, the presence and effects of pre-injury HA, whether episodic or chronic, are other factors needing investigation. Due to limited research, there is an incomplete understanding of the effects of both pre-injury HA and PTH on clinical measures of postural stability and neuropsychological performance. Many factors may play a role in this relationship including type of HA, number of previous concussions, severity of previous concussions, location/severity of impact, and severity of current injury. Literature provides evidence that all of these factors play a role in the manifestation and duration of symptoms. Guskiewicz et al (2003)(Guskiewicz et al., 2003) reported that 30% of individuals suffering from 3 or more concussions had symptoms lasting greater than one week compared to 14.6% of individuals with history of only one previous concussion. One of the few studies involving HA and concussion reported increased presence of symptoms as well as severity in individuals with a higher PTH score. (Collins et al., 2003) Although there is a relationship between number of previous concussions, symptom presence and other clinical measures, the role of HA in this relationship is poorly understood.

Statement of the Problem

Clinical outcome measures provide clinicians with valuable information regarding an injured individual's recovery. The presence of certain symptoms is one of the most common clinical signs that there is disruption in normal brain function. With headache being the most common of these symptoms, its effects on clinical measures is important to clinicians in management and RTP decisions. Therefore, the purpose of this study was to examine the effects of PTH and pre-injury assessment headache (PAH) on clinical measures of concussion as measured by the Automated Neuropsychological Assessment Metric (ANAM), the Balance Error Scoring System (BESS), the Standard Assessment of Concussion (SAC), and a graded symptom check list (GSC). Our second purpose was to examine the association between frequency of previous concussion and PAH as well as PTH.

Research Questions

1. Do individuals reporting PAH have a higher frequency of previous concussion than individuals who do not report headache at baseline?
2. Do individuals reporting PTH at day 1 post-injury have a higher frequency of previous concussion than individuals who do not report PTH?
3. Do individuals reporting PAH report an increased number of symptoms, and/or display increased deficits on clinical measures when measured on SAC, BESS and a GSC at baseline, day 1 post-injury, day 3 post- injury, and day 7 post-injury compared to individuals reporting no PAH?

4. Do individuals reporting PAH display increased neuropsychological deficits at baseline, sub- acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7) compared to individuals reporting no PAH?
5. Do individuals reporting different severities of PTH at day 1 post-injury report an increased number of concussive symptoms and/or display increased deficits on clinical measure when measured on, SAC, and BESS and a GSC at day 1 post injury, day 3 post-injury, and day 7 post-injury when compared to individuals reporting no PTH?
6. Do individuals reporting different severities of PTH display increased neuropsychological deficits at baseline, sub- acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7) when compared to individuals reporting no PTH?

Null Hypotheses

1. H_o: Individuals reporting PAH will not have a higher frequency of previous concussion than individuals who do not report headache at baseline.
2. H_o: Individuals reporting PTH at day 1 post injury will not have a higher frequency of previous concussion than individuals who do not report PTH.
3. H_o: Individuals reporting PAH will not differ statistically in, number of symptoms, or on clinical measures scores when measured on a GSC, SAC, and BESS at baseline, day 1 post injury, day 3 post injury, and day 7 post injury when compared to individuals with no PAH.

4. H_o: Individuals reporting PAH will not display increased neuropsychological deficits at baseline, sub- acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7) when compared to individuals reporting no PHA.
5. H_o: Individuals reporting PTH on day 1 post injury will not report an increased number of concussive symptoms and display increased deficits on clinical measures when measured on a GSC, SAC, and BESS on day 1 post injury, day 3 post injury, and day 7 post injury when compared to individuals reporting no PTH.
6. H_o: Individuals reporting different severities of PTH will not display increased neuropsychological deficits at baseline, sub- acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7) when compared to individuals reporting no PTH?

Research Hypotheses

1. H_a: Individuals reporting PAH will have a higher frequency of previous concussion than individuals who do not report headache at baseline.
2. H_a: Individuals reporting PTH at day 1 post-injury will have a higher frequency of previous concussion than individuals who do not report PTH.
3. H_a: Individuals reporting PAH will report an increased number of symptoms, and will display increased deficits on clinical measures when measured on a GSC, SAC, and BESS at baseline, day 1 post injury, day 3 post injury, and day 7 post-injury compared to individuals with no PAH.
4. H_a: Individuals reporting different severities of PAH will display increased neuropsychological deficits at baseline, sub-acutely after injury (post-injury d1-d2),

and/or prolonged after injury (post-injury d5-d7) when compared to individuals reporting no PAH when compared to individuals not reporting PTH.

5. H_a: Individuals reporting PTH on day 1 post-injury will report an increased number of other concussive symptoms and display increased deficits on clinical measures measured by GSC, SAC, and BESS at day 1 , day 3 and day 7 post-injury when compared to individuals reporting no PTH.

6. H_a: Individuals reporting different severities of PTH will display increased neuropsychological deficits at baseline, sub-acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7) when compared to individuals reporting no PTH?

Definition of Terms

1. Neuropsychological Testing- assessment of cognitive function using brain-behavior relationships

2. Automated Neuropsychological Assessment Metric- computerized neuropsychological assessment battery

3. Mental Status Testing- assessment of neurocognition including orientation and mental processing

4. Standard Assessment of Concussion- an objective clinical mental status screening assessing orientation, immediate memory, concentration, and delayed recall. (McCrea, 2001b)

5. Balance- maintaining the center of gravity within the body's base of support

6. Balance Error Scoring System- clinical field test used to evaluate postural stability following a concussion. (Guskiewicz, Ross, & Marshall, 2001; Riemann BL, 2000)

7. Graded Symptom Check List- a 7 point Likert scale checklist of 20 symptoms including headache, nausea, vomiting, disturbed balance /dizziness, fatigue, disrupted sleep, drowsiness, sensitivity to light, blurred vision, sensitivity to noise,

joint stiffness, sadness, numbness/tingling, feeling like in a fog, poor concentration , difficulty with memory , and neck pain

8. Concussion-An injury resulting from a blow to the head causing an alteration in mental status and 1 or more of the following symptoms: headache, nausea, vomiting, dizziness/balance problems, fatigue, difficulty sleeping, drowsiness, sensitivity to light or noise, blurred vision, memory deficits, and difficulty concentrating.(Guskiewicz et al., 2003; McCrea et al., 2003)

Operational Definitions

1. Post-traumatic Headache (PTH)- headache resulting from trauma to the brain/head reported at day 1 post-injury
2. Mild Post-traumatic Headache: a post-traumatic headache score of 1-2 on GSC
3. Moderate-Severe Post-traumatic Headache: a post-traumatic headache score of 3-6 on GSC
4. Post-traumatic Migraine (PTM)- post-traumatic headache presenting with nausea and/or photophobia and phonophobia
5. Chronic Headache (CHA) -Presence of HA three or more days per week as measured by GSC as pre-season baseline
6. Mild Chronic Headache-a baseline headache score of 1-2 on the GSC.

9. Moderate-Severe Chronic Headache-a baseline headache score of 3-6 on the GSC.
10. Pre-Season Assessment Headache- Headache experienced 3 or more days per week on a regular basis reported on the GSC during pre-season assessment

Assumptions

1. Subjects performed to the best of their ability on the ANAM, SAC, and BESS.
2. Subjects were truthful when providing information regarding concussion history and presence/severity of symptoms
3. ANAM, SAC, BESS and the GSC are valid and reliable clinical measures of concussion.

4. The participating certified athletic trainers followed the guidelines of the study when evaluating a concussion.

5. The experimenter administered the tests properly.

Delimitations

1. Only individuals reporting HA at day 1 post-injury were included in the PTH groups.

2. Only individuals reporting HA at baseline were included in the pre-season assessment HA groups.

3. Only ANAM, SAC, BESS, and a GSC were used as measures of postural stability and neuropsychological performance.

Limitations

1. Different Certified Athletic Trainers (ATC) evaluated the concussed subjects.

2. There were a limited number of subjects with ANAM as a clinical measure.

3. The GSC, history of concussion questionnaire, and the headache questionnaire is based on self-reported information.

4. A greater number of males than females were included.

5. Only a small number of participants were included in the subgroup who completed ANAM at all test times included in the study.

Significance

Headache, whether atraumatic or traumatic, may cause alterations in cognitive function affecting an individual's activities of daily living. Although headache is common, even without the presence of trauma, the relationship of headache to recovery from concussion is poorly understood. The effects of PTH and PAH on clinical measures as well as, recovery, and symptom presence and severity are also a topics needing further research. Very few studies discuss the effects of headache on clinical measures of concussion. This study attempted to answer these questions, so that clinicians will better understand how to interpret post-concussion scores on the GSC, ANAM, SAC, and BESS following concussion. Understanding these effects will ultimately lead to improved management and RTP decisions following sports-related concussion.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Over the past 15 years, sports-related concussion has become a highly researched topic among the medical community and accounts for approximately 5.5% of total injury in athletics each year. (Powell & Barber-Foss, 1999) Although concussion is a commonly discussed topic, there are many areas still in need of investigation. Concussion may be associated with a variety of neurological symptoms lasting for varying periods of time. The most often considered of these symptoms are loss of consciousness and LOC and post-traumatic amnesia PTA. Although these two symptoms may be indicators of neurological deficiency, they are not the only indicators of brain function or injury severity. LOC and amnesia occur in 9% and 23% of concussions reported. (Guskiewicz, Weaver, Padua, & Garrett, 2000) Therefore, other symptoms such as headache and clinical measures should be considered in evaluation and management of concussion.

Concussion/Mild Traumatic Brain Injury

Concussion is a mild traumatic brain injury (MTBI) typically resulting from acceleration-deceleration forces. Forces great enough to produce concussion may result in a variety of symptoms due to the resulting metabolic dysfunction occurring in the brain. (Giza & Hovda, 2001) Most commonly these symptoms include headache, photophobia, phonophobia, nausea, dizziness, balance disturbances, attention deficits, memory problems, fatigue, and drowsiness. Other post concussive symptoms may include LOC, PTA, blurred vision, and nausea. Individuals may present with symptoms for minutes to days depending on location of impact, severity of injury, number of previous concussions, and other factors specific to each individual injury. (Guskiewicz et al., 2005; Guskiewicz et al., 2003; Pellman, Viano, Tucker, & Casson, 2003)

Evaluation of Concussion

Evaluation and management of concussion requires a multi-factorial approach that involves a compilation of clinical assessments. Pre-injury baseline assessment of clinical measures is recommended in order to establish normative information on each individual athlete.   Most commonly, these measures include symptom assessment, mental status testing, neuropsychological testing, and postural stability assessment. These four areas may be assessed using a variety of specific clinical measures tests. Thorough and repeated evaluations using these measures are essential in proper management and treatment. Clinicians are encouraged to pay close attention to all signs and symptoms of neurological dysfunction when dealing with a concussion. Symptom resolution is commonly viewed as one the most reliable factors regarding RTP. Presence of any neurological symptom should warrant concern over the possibility of existing neuropathologic issue; therefore, the individual should not be allowed to return to activity until completely asymptomatic with rest and remains asymptomatic following a trial of exertion. (Guskiewicz et al., 2004)

Headache

Headache (HA) is the most common post-concussive symptom (Guskiewicz et al., 2003; Guskiewicz, Weaver, Padua, & Garrett, 2000) and a common occurrence at all levels of sport and in the normal population. Migraine occurs in about 12% of the adult population (16% women and 6% men). Tension type headache overlaps with the migraine group and occurs in about 35% of the population, at some time. Headache may cause significant changes in cognitive ability and level of function. There are many types of headache, each presenting with different clinical signs and symptoms, severity ranges, and varying effects on performance. Chronic daily headache (CDHA), HA of any classification experienced 15 or more days per month or 3 or more days per week, may cause significant limitations in activities of daily living due to the effects of persistent pain. (*The International Classification of Headache Disorders*, 2004) HA in the athletic population is often posttraumatic in origin. Posttraumatic headache (PTH) can be classified as a specific type of headache according to symptoms present. Previous concussions also have an effect on severity and duration of symptoms. Individuals suffering multiple concussions typically present with a greater number and severity of symptoms and a longer duration of these symptoms, including HA. (Guskiewicz et al., 2003)

Purpose

Although HA is the most common concussive symptom, its relationship to clinical measures is poorly understood. Although the literature suggests a relationship of symptoms to defined clinical measures, there are few specific studies investigating the effects of HA on those measures. (Collins et al., 2003; Mihalik et al., 2005) Additionally, much research has focused on the effects of multiple concussions. Few, if any studies examine the specific relationship of HA and multiple concussions. Through this study, we investigated the effects of both PAH and PTH on clinical measures of concussion as measured by ANAM, SAC, BESS and a GSC and to assess the effect of multiple concussions on HA presence and severity, both pre- and post-injury.

Sports-Related Concussion/MTBI

Definition

Concussion is commonly defined as a transient alteration in neurological function caused by trauma to the brain; however, there is ambiguity regarding terminology concerning MTBI due to the compilation of multiple neurological symptoms that may result from concussive injury. The terms concussion, mild head injury (MHI), and mild traumatic brain injury (MTBI) are used interchangeably throughout literature. Although there are discrepancies in terminology, most clinicians and researchers agree that concussion is a serious injury and requires thorough and repeat evaluations.

Discrepancies also exist among grading systems and return to play (RTP) guidelines. There are numerous classification systems categorizing concussion severity; however, few of these systems have been universally accepted. These classification systems often address LOC and PTA but fail to emphasize the importance and relevance of more common symptoms such as headache and dizziness as symptoms such as PTA andLOC are very easily recognizable upon initial evaluation, and the others may manifest over time. (Guskiewicz et al., 2004)

Epidemiology of Concussion

There are approxiamtely 300,000 sports-related brain injuries each year in the United States. (Thurman, Branche, & Sniezek, 1998) These injuries occur in a variety of sport-related activities across all age groups. In the United States, football is the leading cause of sports-related trauma but many other sports have a high occurrence of concussion. Nearly 250,000 football related brain injuries occur each year. (Thurman, Branche, & Sniezek, 1998) The incidence may even be higher as many injuries go unreported. The incidence of concussion in high school football may be as high as 15% of all players. (McCrea, Hammeke, Olsen, Leo, & Guskiewicz, 2004) Among high school athletics, football, wrestling, soccer, and basketball account for the highest incidence of reported concussions. (Powell & Barber-Foss, 1999) Around 3 % of all sports-related injuries reported in emergency rooms (ER) are head injuries with males under 20 being the most common population reported. Ice hockey and cycling account for the largest percentage of sport-related head injuries seen in the ERs each year. (K. D. Kelly, Lissel, Rowe, Vincenten, & Voaklander, 2001) Although 90% of brain injuries reported to the ER are mild, there are approximately nine-hundred deaths per year attributed to brain injury. (Sosin, Sniezek, & Thurman, 1996) Elite soccer also has a high incidence of concussion. Studies indicate that up to 52% of both male and female soccer players have suffered at least one concussion in their career.(Barnes et al., 1998) Male soccer players are at an increased risk of sustaining a concussion. The ratio of concussions between male and female elite soccer athletes is approximately 2:1. (Barnes et al., 1998; Boden, Kirkendall, & Garrett, 1998) With increased involvement in athletics across all age groups, the incidence of concussion is likely to increase as the number of exposures to injury increases. Although the occurrence of severe injury has decreased; current research suggests that the effects of MTBI are more severe than originally thought.(Bailes & Cantu, 2001; Guskiewicz et al., 2005; Guskiewicz et al., 2003) Therefore, it is important to be aware of at risk sports and individuals in order to aid in prevent this serious and often overlooked injury.

Biomechanics/Mechanism of Injury

Numerous conditions predispose and individual to concussive injury to occur in athletics. Another player, coming in contact with the ground, or a blow to the head may produce an acceleration-deceleration type force. Whiplash type injuries may also produce acceleration-deceleration type forces. These injuries can produce linear and rotational forces transmitted through central nervous system tissues. The vector of impact, head-neck anatomic features, and musculoskeletal structures all influence the distribution of linear and rotational forces. (Barth, Freeman, Broshek, & Varney, 2001; Pellman, Viano, Tucker, & Casson, 2003) The cranium may also be fixed during a concussion injury resulting in linear and tensile strains that can disrupt cerebral function. Greater CNS disfunction is seen in injures with multiple vectors of acceleration and deceleration in response to forces within the cranium. This type of injury usually leads to greater neurological dysfunction implicating the effects of multiple force vectors on functional outcome. (Barth, Freeman, Broshek, & Varney, 2001) In professional football, the average impact velocity is 9.3 m/s; the average head velocity change has been suggested to be 7.2 meters per second; the average head acceleration is 98 g. Although these studies give basic information on impacts, there are limitations due to perception and angle of the camera used to determine direction, duration, and location of the impacts. (Pellman, Viano, Tucker, & Casson, 2003) Currently, there is new technology using in-helmet accelerometers to gain this information from a more scientific and mathematical perspective. (Duma et al., 2005) However, questions have been raised concerning whether the impact being measured is the force through the helmet or the head. Research is currently being conducted using this new methodology to refine the instruments and to investigate the relationship of impact direction, magnitude, duration, and location to concussive symptoms and effects. Although currently under further investigation, the exact causative factors of a concussion are difficult to determine. Forces transmitted through the brain may be a result of focal or generalized (diffuse) trauma. Focal trauma usually occurs as a result of a direct blow and often results in brain contusions, macroscopic lesions and intracerebral bleeding. Generalized or diffuse injury varies from mild to severe and is often a result of shearing forces transmitted through the brain. (Davis & McKelvey, 1998; Jamieson & Yelland, 1972) Whether the force is linear, rotational, or angular, when cognitive deficits result the condition is serious and needs on going assessment. It is important to understand the mechanism of injury (MOI) in order to ascertain the possible causes of the resulting injury.

Pathophysiology of Concussion

Trauma to the brain causes a neurometabolic cascade of events that result in a variety of neurological symptoms. These deficits are transient and usually show no anatomic abnormalities, leading to the belief that the damage is due in large part to neuronal dysfunction and not cell death. Disruption of neural membranes, axons, and opening of voltage dependent potassium (K+) channels lead to an increase in extracellular K+ which in turn may lead to massive excitation commonly referred to as spreading depression. This spreading depression is likely the cause the early post-concussive symptoms such as amnesia and LOC. (Bull & Cummins, 1973; Mayevsky & Chance, 1974) In an effort to maintain homeostasis, energy requiring membrane pumps are activated and trigger an increase in glucose usage. An increased use of adenosine triphosphate (ATP) occurs in an attempt to maintain this balance resulting in a state of hyperglycolysis. As this hypermetabolism occurs, there is diminished cerebral blood flow, a lactate compensation stage begins, there is disparity between glucose supply and demand which triggers this energy crisis at the cellular level. (Gardiner, Smith, Kagstrom, Shohami, & Siesjo, 1982; Giza & Hovda, 2001; Takahashi, Manaka, & Sano, 1981; Yang, DeWitt, Becker, & Hayes, 1985) The immediate decrease in cerebral blood flow can be as high as a 50% reduction, which is not enough to cause ischemia, but may worsen the already vulnerable neurons effort to maintain electrolyte balance. (Yamakami & McIntosh, 1989; Yuan, Prough, Smith, & Dewitt, 1988) Together, all of the processes produce neurological dysfunction leading to deficits in cognitive function, mental status, and changes in other neurological functions. While this imbalance is present, the brain is in a vulnerable state underscoring the importance of only returning to activity when no indicators of disruption are present.

Signs and Symptoms

Concussion is an individualized injury producing neurological deficits and symptoms of variable severity. The most common of these symptoms is headache, which occurs in up to 86% of concussed individuals. (Guskiewicz et al., 2003; Guskiewicz, Weaver, Padua, & Garrett, 2000) This post-traumatic headache (PTH) can manifest in many different forms ranging from post-traumatic migraine to episodic tension like headache. Although not as common, LOC and amnesia are two of the most often considered results of concussion and are the two most commonly used symptoms in the grading scales available. These two symptoms are often thought of as hallmarks of concussion; however, they do not manifest in most cases. Loss of consciousness (LOC) occurs as a result of external forces affecting head movement that cause mechanical forces to be transmitted through the brain producing sudden electric discharge or depolarization of nerve cells leading to the actual LOC. Studies in the literature suggest that the altered glucose metabolism is not the causative factor relating to LOC. Although it is a less common symptom, it is an important piece of the concussion puzzle and it should be determine if it actually did occur following a concussive injury. (J. P. Kelly, 2001) Amnesia may occur in two forms. Retrograde amnesia refers to partial or total loss of ability to recall events that have occurred during the period proceeding brain injury; whereas anteriograde amnesia is a deficit in forming new memory. Both types of amnesia are post-traumatic due to the fact that both types occur following trauma to the brain. Many individuals consider antergrade amnesia the most sensitive indicator of brain function. Amnesia usually results from involvement of the cerebral cortex, subcortical projections, hippocampal formation and diencephalon. (Cantu, 2001) Another common deficit after concussion involves postural stability. Postural stability is often defined as the ability to maintain the body's center of mass over a base of support. Numerous mechanisms allow the brain to process information and give appropriate feed back regarding balance and postural stability. Disruption to the normal brain processes may cause postural stability deficits leading to balance disturbances. These disturbances are likely a sensory integration dysfunction that prevents concussed individuals for using information accurately and exchanging sensory information from the somatosensory, visual, and vestibular systems therefore causing equilibrium dysfunction. (Guskiewicz, 2003; Guskiewicz, Ross, & Marshall, 2001) Because it involves neuromuscular components, postural stability may also be largely affected by other factors such as fatigue; therefore, emphasizing the importance of baseline and serial testing.(Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004) Mental status may also be affected following a concussive injury. Commonly, mental status exams assess orientation, immediate memory, delayed recall, and concentration. Following a concussion there is usually marked deficits in these measures. Although orientation is usually a portion of assessing mental status, it is significantly less sensitive to neurocognitive functioning.(McCrea, 2001b; McCrea et al., 2003) Loss of conciousness (LOC) and amnesia may also serve as an indicator of greater neurocognitive deficits following concussion. Individuals suffering from LOC or amnesia are more likely to have greater neruocognitive deficits post-injury. (McCrea, Kelly, Randolph, Cisler, & Berger, 2002) Cognitive impairment is often most significant at the time of injury (TOI) and balance deficits are most prominent during the first 24 hours post injury. Other common symptoms occurring post injury include visual disturbances, dizziness, nausea, drowsiness, attention deficits, difficulty concentrating, personality changes, fatigue, memory deficits, photophobia, and phonophobia. (McCrea et al., 2003) Attention deficits, mental processing impairment, and concentration problems are deficits in neuropsychologic function. (Bleiberg et al., 2004; Collins et al., 1999; Echemendia RJ, 2001; Guskiewicz, Ross, & Marshall, 2001) Post-injury, most concussive symptoms resolve in 7-10 days; however, These symptoms may vary depending on injury severity, location of impact, number of previous concussions, and other individualized factors.(Bleiberg et al., 2004; McCrea et al., 2003) Previous history of concussion also plays a significant role in the way an individual physiologically responds to a succeeding injury. Current literature suggests a link between number of previous concussions and duration of concussive symptoms, prevalence of post-concussion syndrome, and susceptibility to another injury. The NCAA concussion study displayed that 30% of individuals with three or more concussions reported symptoms last greater than one week compared 14.6% of individuals who only experienced one previous concussion.(Guskiewicz et al., 2003) Studies have also shown that most recurrent injuries occur within 7 days of the previous injury implicating the importance of confirming that an individual is asymptomatic before allowing to return to play. (Collins et al., 2002; Guskiewicz et al., 2003) Currently, there is further research being conducted examining the effects of pediatric concussion on individuals later in life and further research being conducted on lingering effects of concussion at months and years succeeding injury.

Management and Return to Play

Currently there is no gold standard regarding RTP and management of sports-related concussion. There are numerous grading scales using various periods and symptoms to assess degree of severity and guidelines for RTP. Although there is variability, there is a consensus that the most important RTP guideline is presence of symptoms. No individual should be allowed to RTP while symptomatic. In order to manage brain injuries appropriately an injured individual should be repeatedly evaluated and monitored. One of the first considerations in acute management is ruling out more severe injuries such as hematomas or skull fractures. Secondly, clinicians should be aware of and be able to recognize at risk individuals so to recognize injuries early and take appropriate action. (Collins & Hawn, 2002) Thirdly, education is essential. Injured individuals and people in close proximity to them should be educated on the signs to look or in case of a more severe condition. Studies have shown education to play a major role in reporting and management of injuries. One study reported that up to 20% of concussions may go unreported and inadequate education may play a large role in this risky behavior.(Kaut, DePompei, Kerr, & Congeni, 2003) Recently the National Athletic Trainers' Association published a position statement regarding sports-related concussion and made the recommendation for thorough and complete evaluations consisting of neuropsychological assessment, mental status assessment, postural stability assessment, and symptom assessment. Together, these four pieces of information can give an objective measure of how to manage the individual situation appropriately. (Guskiewicz et al., 2004)

Clinical Measures of Concussion

The complexity of RTP decisions and management are two of the most difficult issues facing the sports medicine community. There is debate among clinicians regarding the numerous grading scales, terminology, and management. Over the past few years, clinicians and researchers have worked diligently to develop and validate reliable, objective measures assessing both the cognitive and neurological deficits following concussion. Recent studies suggest thorough post-injury assessment should consist of an assessment of symptoms, postural stability, neuropsychological deficits, and mental status. (Guskiewicz et al., 2004) Baseline testing on these same measures is also recommended due to the individual variability regarding these clinical measures. There are various measures to assess these factors and objectively assess a concussive injury. Some of the most commonly used are a

GSC, a mental status testing instrument, a clinical postural stability test, and a computerized neuropsychological test battery.

Graded Symptom Checklist

Commonly, a GSC is used in order to gain information regarding the concussed individual's symptom presence and severity. This GSC is most commonly a 20-item checklist that allows the patient to rate concussive symptoms on a scale of 0-6 according to severity. It is important to have a baseline score for this measure in order to know what is normal for the athlete in a non-injured state. Researchers have cited this form of self-report symptom scale as a practical measure for monitoring symptoms.(Maroon et al., 2000; P. R. McCrory, Ariens, & Berkovic, 2000) Although it is practical and allows the individual's input, there are limitations. The two most prevalent limitations are the honesty and the motivation of the patient when responding to the GSC.

Mental Status Testing

Mental status testing involves the assessment of acute neurocognitive effects of concussion. Traditionally, mental status assessment consisted of a qualitative, subject assessment of whether the injured individual was "normal" with no reference to the individual's status prior to injury. As with other concussive measures, mental status testing has become more standardized involving instruments such as the Standardized Assessment of Concussion (SAC). This instrument assesses immediate memory, delayed recall, concentration, and basic orientation. It also allows exertional maneuvers to be performed to test the patient under physical stress if needed. The total numerical score possible on the SAC is a thirty- with up to five points for orientation, five points for immediate memory, five points representing concentration and five points for delayed recall. Time for administration is approximately five to ten minutes and the instrument can be administered by a non-neuropsychologist. There is normative data representing over 2500 male and female athletes across all levels of athletics suggesting that the instrument is both valid and reliable for the use at all educational and competitive levels.(McCrea, 2001a; McCrea, Kelly, & Randolph, 2000) Numerous studies suggest the validity of the SAC to detect mental status deficits resulting from concussion. (McCrea, 2001a, 2001b; McCrea, Kelly, Randolph, Cisler, & Berger, 2002) One study displays a decline of one point or more from an individual's baseline score results in a 94% sensitivity and a 76% specificity in accurately differentiating between injured and non-injured individuals.(Barr & McCrea, 2001) Although the SAC is both valid and reliable, it is only one of the pieces that should be used in evaluation of concussion.

Postural Stability Testing

Balance is often affected following a MTBI due to dysfunction in sensory integration. Numerous studies report deficits following injury. These studies also indicate a recovery of postural stability around 7-10 days post-injury (Guskiewicz, 2001, 2003; Guskiewicz, Ross, & Marshall, 2001; Peterson, Ferrara, Mrazik, Piland, & Elliott, 2003; Riemann BL, 2000) Assessment of postural stability can be obtained by many methods. Some of the most common include the subjective Rhomberg Test, the Balance Error Scoring System (BESS) (Riemann BL, 2000) or the use of force plates. Each of these measures provides feedback on an individual's performance post-injury. The BESS is one of the most practical for clinical use, as it is inexpensive, relatively easy to administer, and can be done on the field. The BESS is a clinical field test using six twenty second trails of three different stances (double leg, single leg, tandem) on two different surfaces (firm, foam) . Errors are recorded if the individual lifts hands off of their iliac crest, abducts or flexes their hip to greater than thirty degrees, steps, stumbles or falls, opens eyes, or remains out of the testing position for greater than five seconds. A higher score indicates a greater deficit in postural stability. Due to individual variability, baseline measures are important to determine the severity of deficit following injury. (Riemann BL, 2000) Fatigue has been shown to play a role in decreasing postural stability and should be taken into account upon evaluation.(Wilkins, Valovich McLeod, Perrin, & Gansneder, 2004) The BESS has also been shown to elicit a practice effect after repeat administrations (Valovich, Perrin, & Gansneder, 2003) There are significant correlations between the BESS and force-platform sway measures established using normal subjects on single-leg stance-firm surface, tandem stance-firm surface, double leg stance-foam surface, single leg stance-foam surface, and tandem stance-foam surface. Intertester reliability coefficients range from 0.78-0.96.(Riemann, Guskiewicz, & Shields, 1999) Again, although the BESS and/or other postural stability tests provide a valuable piece of information regarding deficits following a concussive injury, it should be used in conjunction with other clinical assessment measures.

Neuropsychological Testing

Neuropsychological testing is a tool used in the evaluation of mild head injuries. This type of testing consists of test batteries that allow for the assessment of inconsistencies among scores measuring various cognitive processes. Neuropsychological testing measures cognitive domains such as attention, learning, memory, mental flexibility, concentration, information processing, reaction time, motor speed and coordination. (Barr, 2001; Collins et al., 1999; Guskiewicz, Ross, & Marshall, 2001; Peterson, Ferrara, Mrazik, Piland, & Elliott, 2003) Testing can be computerized or completed using paper and pencil. Both methods are shown to be sensitive in assessing neuropsychological changes following and MTBI. Due to the standardization and decreased administration time, computerized testing is commonly used. There are four computerized testing batteries often used in the evaluation of MTBI. CogSport which assesses reaction time, attention, working memory, short term memory, new learning, incidental memory, and adaptive problem solving. (Rietdyk, Patla, Winter, Ishac, & Little, 1999) HeadMinder uses an online neurocognitive and neurobehavioral assessment battery in the form of the Concussion Resolution Index (CRI) and the Sideline Assessment (SA). (Erlanger, Feldman, & Kutner, 1999) The third of these computerized batteries is ImPact which contains a self-report GSC, a concussion history form and assesses attention, memory, processing speed and reaction time.(Lovell, Collins, Podell, Powell, & Maroon, 2000) The fourth is the Automated Neuropsychological Assessment Metrics, which consists of 5 testing modules with two of these modules being repeated at the end of the testing battery. ANAM assesses reaction time, visual memory, concentration, working memory, mental processing speed, and mental efficiency. ANAM uses a throughput score based on the number of correct responses per unit of time. This score is the product of both speed and accuracy providing a single efficiency score. Each testing session contains a different combination of items to minimize the possibility of practice effects. (Bleiberg et al., 2004; Bleiberg, Halpern, Reeves, & Daniel, 1998) Neuropsychological testing has the advantage of detecting subtle cognitive deficits; however, in order to appropriately administering these batteries and interpret the results accurately, the tester must be properly trained. This limits the amount of individuals able to use this tool.

Factors Affecting Neuropsychological Performance

There are many factors that may contribute to decreased neuropsychological performance. In order for clinicians to better understand this clinical measure, factors that may affect it must also be understood. Literature suggests connections between concussion severity, number of previous concussions, and neuropsychological performance. (Collins et al., 1999; Echemendia RJ, 2001; Guskiewicz, Ross, & Marshall, 2001) Therefore, an appropriate medical history is important when considering neuropsychological performance. The portions of a neuropsychological evaluation most often affected include speed of information processing, planning, and short-term visual memory.(Mrazik et al., 2000) Other factors that may influence or affect these scores include gender, fatigue, anxiety, practice affects, and pain. In high school athletes, females may display increased mean scores on processing speed, mental tracking and verbal initiation tasks. Many of these factors tie into each other and may create a cycle that leads to the decrease a clinician may see. (Barr, 2001) Practice effects have also been shown to influence scores . Pain may also be a contributing factor. A review article found a common association of pain with attention, memory, processing speed, and reaction time deficits. This suggests the influence of pain on cognitive impairment.(Hart, Martelli, & Zasler, 2000)

Headache

Headache may present in many ways both prior to and following a concussive injury. Headache is a common condition across all ages and groups of people. In the athletic population, there are many possible causes for HA. Exertional HA is the most common type in this population. (P. McCrory, 2001) This type of HA is a result of exertion with no other underlying conditions to cause the HA. Posttraumatic headache (PTH) is also a common occurrence in athletics. Athletes like any one else may experience migraine, tension- type headache (TTH), HA of cervical origin or a combination of HA type. Approximately 47 million individuals in the United States suffer from headache on a regular basis at some point during their lifetime. The International Headache Society has numerous classifications for headache. These classifications serve as guidelines for placing HA into a specific category. Any type of headache can be episodic or chronic, depending on the time of persistence. The IHS defines types of chronic HA as HA that occurs greater than 15 days pre month over a period greater than three months. Most classifications of HA may present pre or post-trauma and can be classified as either episodic or chronic.

Pathophysiology in relation to MTBI

Although little is understood relating to the pathophysiology of PTH and PTM, recent literature suggest similarities to the pathogenesis of MTBI especially in regards to PTM and PTH. Both MTBI and migraine result in an increase in extracellular potassium, intracellular sodium, calcium, and chloride. Both may also result in excessive release of amino acids. (MTBI-glutamate, Migraine-glutamate, asparate) These two conditions also involve neurotransmitter dysfunction, which may lead to spreading depression. With both conditions, there is also a magnesium deficiency.(Browndyke, 2000; Packard RC, 1997; Shaw, 2002) Overlapping physiological responses may offer some suggestions as to why an athlete reporting PTH may experience further deficits.

Chronic Headache

Chronic headache, commonly referred to as chronic daily headache (CDHA) may manifest in many forms and present a variety of problems for an individual suffering from this condition. As with most headache types, these headaches can be of primary or secondary origin. Medicine overuse, specifically analgesic overuse is one of the most common secondary factors producing CDHA. (Granella et al., 2000; Spierings, 2003) According to current literature, the majority of CDHA suffers experience migraine without aura as the episodic type of HA that precedes the CDHA form. (Goadsby & Boes, 2002; Granella et al., 2000; Spierings, 2003) The majority of CDHA sufferers also have the onset of chronicity before 30 years of age. CDHA is more prevalent in women than men, with approximately 81% of suffers being female.(Spierings, 2003) One study, analyzing clinical and descriptive information relating to CDHA found that around 46.5% of individuals diagnosed with CDHA suffer from chronic coexisting migraine and tension type HA. Although around 3-5% of the general population suffers from this frustrating condition, little is understood about the physiology around why this chronicity occurs. One theory behind CDHA is a lower recruitment of descending pain inhibitory systems related to psychological factors. Prolonged episodic bouts with TTH may produce prolonged nociceptive stimuli from myofascial tissue and may be a fundamental factor in the conversion of HA to the chronic form. Secondary, segmental sensory sensitization and/or an impaired supraspinal modulation of incoming stimuli may also play a role. (Spierings, 2003) Literature supports neuropsychological findings suggesting a common neuronal dysfunction predisposing an individual to primary HA subtypes such as the influence of peripheral muscles and as previously mentioned, dysfunction in central nociceptive modulation. CDHA often affects activities of daily living. A study examining headache level during neuropsychological testing found that headache level did not influence scores on this particular paper/pencil testing battery and that a significant number individuals who began the battery with no HA did not develop a HA during the testing process. However, a significant number of individuals who began with a headache had an increase in pain over the course of the testing battery. (Lake, Branca, Lutz, & Saper, 1999) This study however is limited by no within subjects design in testing the subjects asymptomatically and at different levels of pain. The study also did not take into account the use of medications, which may alter neurocognition. There are studies that display effects of pain, specifically chronic pain on neuropsychological test scores indicating a negative effect on neurocognition. (Hart, Martelli, & Zasler, 2000; Hooker, 1986)

Posttraumatic Headache

Both HA and concussion may produce alterations in cerebral blood flow. This abnormal blood flow is thought to be a causative factor regarding most concussive symptoms. (Margulies, 2000) The International Headache Society defines PTH both acutely and chronically. PTH is defined regarding mild head injury (MHI) and moderate to severe injury. MHI post-traumatic headache is headache following trauma with all of the following: LOC for less than 30 minutes, Glascow Coma Scale of 13 or higher, signs and symptoms of concussion, pain developing within seven days following trauma and the headache does not last longer than three months post-trauma. In relation to moderate to severe head trauma the following must apply: headache developing within first seven days post-trauma or within seven days of regaining consciousness, HA resolving within 3 months of trauma and at least one of the following: LOC greater than 30 minutes, PTA lasting longer than 48 hours, imaging display of a traumatic brain lesion. Chronic PTH for both MHI and moderate-severe head injury has the same criteria as the acute counterpart with the exception of the length of time the headache persists. To be considered chronic, the headache must persist for greater than three months. (*The International Classification of Headache Disorders*, 2004) The definition raises questions among clinicians due to the time restraints on when headache may present because some types of PTH may take longer to manifest.

PTH may present in many forms. According to the IHS in 2003, most commonly these headaches are classified as post-traumatic tension type headache (TTH) which accounts for approximately 80% of PTH. TTH is defined either episodically or chronically. These headaches are usually bilateral in location and have tension or pressing properties. This type of headache usually does not present with nausea or vomiting. Post-traumatic Migraine or headache presenting with migraine characteristics is also a problem following head trauma. These headaches usually cause nausea, photophobia and/or phonophobia, visual disturbances, and dizziness. (Solomon, 1998) Some studies suggest that most accounts of PTH have characteristics of migraine and that perhaps the HA itself is cause for many aspects of the post-concussion syndrome. (Margulies, 2000) Footballers Migraine is also a common post-traumatic condition occurring in the athletic population. It is most common in children and adolescents who participate in contact sports. The migrainous attack usually occurs within ten minutes following trauma. These individuals usually have no previous history of migraine under other circumstances. This condition is most often seen in soccer and football and often disappears in late adolescence and early adulthood. In general, the prevalence of headache in football is also relatively high. Studies show the percentage to be as high as 85% of football players who experience headache related to hitting and 80% of these individuals stated that this headache occurred in at least 25% of games played. (Sallis & Jones, 2000) These percentages are both alarming and informative. Due to the high prevalence of HA related to trauma, it is essential that researchers and clinicians gain a more thorough understanding of the relationship of HA to head trauma.

Headache and Clinical Measures

Few studies specifically examine the relationship of HA and clinical measures of concussion. Currently the limited number of studies do show a relationship between PTH and neuropsychological test scores as well as on-field markers of severity such as LOC, amnesia, and symptom presence. (Collins et al., 2003; Mihalik et al., 2005) Both the SAC and neuropsychological testing may be affected by attention and concentration deficits. Pain effects attention and concentration, which may in turn affect these clinical measures. However, the information regarding pre-injury and chronic HA is even more limited. HA occurs in up to 88% of the general population therefore, its effect on clinical measures is an important piece of information for clinicians to have in order to enhance the management and RTP decisions of sports-related concussion.

Rationale for Study

Although HA is a commonly occurring condition atraumatically and traumatically, the effects of pre-season assessment HA and PTH on clinical measures of concussion is poorly understood. There are few studies regarding HA and concussion. Therefore, we investigated the effects of both these HA subtypes on post-concussion measures as well as the effect of previous concussion on the presence on these HA subtypes. As clinicians, it is important to understand the effects of such a common condition on measures of concussion. We also aimed to reinforce the need for both baseline and repeated evaluations regarding sports-related concussion. All of these factors are important in order to improve the management and RTP of MTBI in the athletic population

CHAPTER III

METHODS

Introduction

Clinical evaluation of concussion should involve a thorough assessment of postural stability, neuropsychological testing, symptom assessment, and a mental status examination. Literature suggests these four measures are valuable tools in assessing sports related concussion. Although there are varying tools used to assess these measures, clinicians should be consistent and adherent in following guidelines for these clinical assessment tools. In our study, we followed the directed protocols for the Standardized Assessment of Concussion (SAC), the Balance Error Scoring System (BESS), the Graded Symptom Checklist (GSC), and the Automated Neuropsychological Assessment Metrics (ANAM).

Subjects

Subjects in this study consisted of concussed high school and collegiate athletes (age = 16.65 ± 1.87 years) recruited from 110 high schools and 14 colleges.

Inclusion Criteria

Subjects were included in this study if they suffered a sports related concussion and completed clinical measure baseline and follow-up testing at days 1, 3, and 7 post-injury using a GSC, SAC, and BESS. Subjects also completed testing on ANAM at baseline, a sub-acute post-injury testing date (day 1 or 2 post-injury), and a prolonged post-injury testing date (day 5 or 7 post-injury).

Procedures

This retrospective study used data gathered from 110 high schools and 14 colleges on 247 concussed individuals. All of these individuals completed baseline and serial testing. All subjects completed a GSC and concussion history questionnaire. On the baseline GSC subjects were asked to report and rate symptoms experienced three or more days per week on a regular basis. A subset of 100 of the subjects completed the BESS and the SAC at all test dates. Another subset of 40 of these subjects completed ANAM testing on all testing days. In relation to pre-season assessment HA the subjects were grouped by those with a positive baseline headache score (PHG), and those with a negative baseline headache score (NHG). Three of the clinical measures of concussion were then compared between the two headache groups at baseline and days one, three, and seven post-injury. ANAM results were compared at the sub-acute and the prolonged testing times. Regarding PTH, subject data were stratified by those with no PTH score day one post-injury, those with a mild PTH score (1-2) day one post-injury, and those with a moderate to severe PTH score (3-6) day one post-injury. The same four clinical measures of concussion were then compared between the three PTH headache groups at days one, three, and seven post-injury.

Graded Symptom Checklist

The graded symptom checklist (GSC) is a 7 pt Likert scale grading system that allows individuals to self- report and rate a variety of concussive symptoms. Current literature suggests this to be a commonly used practical measure of symptomology regarding concussion. We used a 20 item checklist in this study.(Appendix 1)

Automated Neuropsychological Assessment Metrics

For the purposes of this study, the Automated Neuropsychological Assessment Metrics (ANAM) was used in assessing neuropsychological function. (Appendix 2) We used five testing modules (simple reaction time, continuous performance test, math processing, Sternberg memory, and match to sample) Simple reaction time (SRT), assesses reaction time. The continuous performance test (CPT) assesses concentration and working memory. Math processing (MTH) assesses mental processing speed and mental efficiency. The Sternberg (STN) memory measures working memory and match to sample (MTS) measures visual memory. We will test on all five of these modules, during each testing session with a second SRT and CPT module being completed . (Bleiberg et al., 2004; Bleiberg, Halpern, Reeves, & Daniel, 1998) We then calculated the overall composite Z-score for the entire battery and the individual throughput scores for each of the seven individual modules. These scores were compared at baseline, a sub-acute post-injury session and a prolonged post-injury session for PAH and at a sub-acute post-injury session and a prolonged post-injury session for PTH.

Standardized Assessment of Concussion

The SAC was used to assess mental status. (Appendix 3) This instrument assesses orientation by asking five general orientation questions; immediate memory by assessing recall of five words; delayed recall by assessing recall of the five words from immediate memory at the end of the test, and concentration bye asking the subject to repeat a string of numbers in reverse order. It has been proven to be both sensitive and specific in detecting mental status deficits and has been used as a valid and reliable instrument across all levels of sport.(McCrea, 2001a, 2001b; McCrea, Kelly, & Randolph, 2000; McCrea, Kelly, Randolph, Cisler, & Berger, 2002)

Balance Error Scoring System

Postural stability testing gives clinicians an important piece of information regarding management and RTP of sports-related concussion. There are a variety of options available to assess postural stability. For the purpose of this study, the BESS was used. The BESS has been proven to be both a reliable and valid measure of postural stability. (Riemann BL, 2000; Riemann, Guskiewicz, & Shields, 1999) We used six twenty second trails on three different stances (double leg, single leg, tandem) on two different surfaces (firm, foam). (Figure 1, Appendix 4) Individuals were asked to perform the single leg balance task on the non-dominant. Dominance was defined by which leg would be used to kick a ball. (Riemann BL, 2000; Riemann, Guskiewicz, & Shields, 1999) Errors were recorded if the individual lifted hands off of their iliac crest, abducted or flexed their hip to greater than thirty degrees, stepped, stumbled or fell, opened eyes, or remained out of the testing position for greater than five seconds. A higher score indicates a greater deficit in postural stability.

Data Analysis

Data analysis were conducted using SPSS 13.0 (Chicago, IL). Scores on the BESS, the SAC, and the GSC investigating the effects of PAH and PTH were analyzed using four

2x4 and four 3x3 repeated measures, mixed model ANOVAs, respectively, when comparing the groups clinical measures scores at baseline, and days one, three and seven post-injury. Scores for ANAM investigating the effects of PAH and PTH were analyzed using fifteen 2x3 and fifteen 3x2 repeated measures, mixed model ANOVAs respectively, when comparing the groups neuropsychological test scores at the sub-acute and prolonged testing sessions. In these analyses, the between subjects factor was the HA group and the within subjects factor was the test day. When comparing previous history of concussion between the two groups regarding PAH, and between the three PTH groups, two Cross tabs/Chi Square analyses were used. The data summary table on page 38 lists the research questions as well as independent variables, dependent variables, and statistical analyses.

Data Summary Table

RESEARCH QUESTIONS	DATA SOURCE	METHODS
1. Do individuals with a baseline PAH score have a higher frequency of previous concussion?	IV: HA Group DV: HA Score on the GSC	Chi Square, Crosstabs Analysis
2. Do individuals reporting PTH at day 1 post-injury have a higher frequency of previous concussion?	IV: HA Group DV: HA Score on the GSC	Chi Square, Crosstabs Analysis
3.Do individuals reporting PAH at baseline have an increased number of concussive symptoms and/or decreased clinical measures scores at baseline and days one, three, and seven post-injury?	IV: HA Group, Day DV: GSC Total Score, Total BESS score, and Total SAC score	2X4 Repeated measures, mixed model analysis of variance for scores across days
4. Do individuals reporting PAH display increased neuropsychological deficits at baseline, sub- acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7)?	IV: HA Group, Day DV: ANAM module scores, Composite ANAM score (Z and T-put)	2X3 Repeated measures mixed model analysis of variance for scores across days
5. Do individuals reporting PTH at day one post-injury have an increased number of concussive symptoms and/or decreased clinical measures scores at days one, three, and seven post-injury?	IV: HA Group, Day DV: GSC Total Score, ANAM module scores, Composite ANAM score, Total BESS score, and Total SAC score	3X3 Repeated measures, mixed model analysis of variance for scores across days
6. Do individuals reporting different severities of PTH display increased neuropsychological deficits at baseline, sub- acutely after injury (post-injury d1-d2), and/or prolonged after injury (post-injury d5-d7)?	IV: HA Group, Day DV: ANAM module scores, Composite ANAM score (Z and T-put)	3X2 Repeated measures mixed model analysis of variance for scores across days

CHAPTER IV

RESULTS

The purpose of this study was to examine the effects of headache on clinical measures of postural stability and neuropsychological performance. This was accomplished by grouping subjects based on a reported headache score at baseline for the first portion of the study and by grouping subjects based on their headache at day 1 post-injury for the second portion of the study. These individuals were tested on four basic clinical measures at serial testing dates. **Tables 1 and 2** provide demographic information on the participants of the study.

Research Questions 1 and 2

We examined the association between pre-season assessment headache (PAH) and history of previous concussions. A Chi Square test of association suggested an association between these two factors ($\chi 2 = 14.48$, df = 3, $p = .002$). A Crosstabs analysis suggested that individuals who reported three or more previous concussions are more likely to report HA at baseline (**Table 6**). We also examined the association between posttraumatic headache (PTH) and history of previous concussion using a Chi Square test of association and Crosstabs **(Table 10).** No significant association was observed.

Research Question Three

Research Question three examined the effects of HA on the graded symptom checklist (GSC), the Standardized Assessment of Concussion (SAC), and the Balance Error Scoring System (BESS) (**Table 3**). A repeated measures ANOVA revealed no significant effects on the BESS. A significant interaction effect ($F_{3,267}$=3.25, p=.027) as well as a main effect of day ($F_{3,267}$=5.18, p=.002) was observed for the SAC. A significant interaction effect was also observed for symptom total score ($F_{3,675}$= 3.41, p=.03) and total number of symptoms endorsed ($F_{3,675}$=5.63, p=.024). A main effect of day was observed for symptom total score ($F_{1,225}$=77.75, p<.005) total number of symptoms endorsed ($F_{3,675}$=108.94, p<.005).

Research Question Four

Research Question four examined the effects of PAH on neuropsychological performance (**Tables 4 and 5**). Repeated measures ANOVAs revealed no significant interactions for any portion of ANAM. A main effect of day was observed for all modules (p<.05).

Research Question Five

Question five examined effects of PTH on a GSC, the SAC, and the BESS (**Table 7**). A repeated measures ANOVA revealed no significant findings pertaining to the SAC. However, a significant interaction effect and a main effect of day were observed for symptom total score ($F_{2,229}$ = 29.75, p <.005; $F_{4,458}$ = 24.98, p<.005) and total number of symptoms endorsed ($F_{1,83}$ = 5.57, p=.019; $F_{4,458}$ = 20.88, p<.005). A significant effect of group was observed for the BESS ($F_{1,84}$=3.10, p=.05). A Tukey post-hoc test revealed this difference to be between the no-PTH group and the moderate-severe PTH group. (p=.05)

Research Question Six

Research Question six investigated effects of PTH on neuropsychological performance (**Tables 8 and 9**). A repeated measures ANOVA revealed no significant interactions for the Z-scores of Simple Reaction time 2, Math Processing, Match to Sample, Sternberg memory or SRT 2. Significant interactions were found for the Z-scores of Composite Score ($F_{2,41}$=4.98, p=0.01), Simple Reaction Time 1 ($F_{2,40}$ = 3.71, p=.03), Continuous Performance Test 1 ($F_{2,45}$ = 4.41, p=.02), and Continuous Performance Test 2 ($F_{2,44}$=4.21, p=.02). A main effect of day (p<.05) was observed for all Z-score modules with the exception of Match to Sample, and Simple Reaction Time 1. Significant interactions were also found for the throughput scores of Simple Reaction Time 1 ($F_{2,40}$=3.36, p=.46), Continuous Performance Test 1 ($F_{2,41}$=3.89, p=.028), Sternberg Memory Search ($F_{2,39}$=3.67, p=.035), Simple Reaction Time 2 ($F_{2,38}$=6.06, p=.005), and Continuous Performance Test 2 ($F_{2,42}$=4.64, p=.015). A main effect of day (p<.05) was observed for all throughput measures except Match to Sample.

Table 1. Age, Height, and Weight Means and Standard Deviations

	Mean	SD (±)
Age (years)	16.65	1.87
Height (in)	69.40	3.73
Weight (lbs)	172.67	40.53

Table 2. Sport and Gender Frequencies and Percents

	Frequency	Percent
Gender		
Male	301	80.30%
Female	74	19.70%
Sport		
Football	239	63.70%
Hockey	5	1.30%
Lacrosse	40	10.70%
Soccer	89	23.70%
Other	2	1.30%

Table 3. Pre-Season Assessment Headache Clinical Measures Means and Standard Deviations

	Baseline	Day 1 post-injury	Day 3 post-injury	Day 7 post -injury	Group Main Effect	Group X Day Interaction	Day Main Effect
Symptom Total							
No PAH	1.62 (3.47)	10.99 (12.98)	5.55 (10.37)	1.96 (6.48)	$F_{1,225} = 3.175$	$F_{3,675} = 3.414$	$F_{3,675} = 77.75$
+ PAH	5.65 (6.41)	13.56 (13.13)	6.46 (9.92)	1.60 (4.56)	$p = .076$	$p = .033$	$p < .005$
	2.74 (4.82)	11.70 (13.04)	5.80 (10.23)	1.86 (5.99)			
Symptoms Endorsed							
No PAH	0.91 (1.59)	4.80 (4.11)	2.77 (3.95)	0.92 (2.39)	$F_{1,83} = 5.57$	$F_{3,675} = 5.63$	$F_{3,675}=108.94$
+PAH	2.86 (2.84)	5.76 (3.99)	3.28 (3.56)	0.83 (1.83)	$p = .019$	$p = .024$	$p < .005$
	1.45 (2.12)	5.07 (4.09)	2.92 (3.85)	0.89 (2.24)			
SAC Total Score							
No PAH	26.85 (1.64)	26.62 (2.79)	27.62 (1.72)	26.08 (1.74)	$F_{1,89} = .283$	$F_{3, 267} = 3.250$	$F_{3, 267} = 5.18$
+PAH	27.35 (1.85)	26.88 (1.79)	26.73 (2.66)	27.46 (1.66)	$p = .596$	$p = .027$	$p = .002$
	26.99 (1.71)	26.69 (2.54)	27.36 (2.59)	27.90 (1.73)			
BESS Total Score							
No PAH	11.85 (4.76)	14.23 (7.11)	11.13 (6.65)	9.60 (5.66)	$F_{1,83} = .030$	$F_{3,249} = .202$	$F_{3,249} = 15.99$
+PAH	11.20 (4.27)	14.08 (7.27)	11.52 (4.58)	9.24 (4.86)	$p = .863$	$p = .869$	$p < .005$
	11.66 (4.60)	14.19 (7.12)	11.25 (6.02)	9.50 (5.42)			

Table 4. Pre-Season Assessment Headache ANAM Z- Scores Means and Standard Deviations

	Baseline	**Sub-Acute post-injury**	**Prolonged post-injury**	**Group Main Effect**	**Group X Day Interaction**	**Day Main Effect**
Composite Z						
No PAH	0.18 (2.37)	-0.02 (6.13)	4.13 (5.40)	$F_{1,48} = .024$	$F_{2,96} = 2.38$	$F_{2,96} = 15.37$
+ PAH	2.43 (3.58	-1.67 (6.68)	4.12 (6.35)	$p = .877$	$p = .098$	$p < .005$
	0.86 (3.53)	*-0.51 (6.33)*	*4.12 (5.66)*			
SRT 1						
No PAH	0.32 (0.94)	0.13 (1.27)	0.47 (1.13)	$F_{1,44} = 1.28$	$F_{2,88} = 1.68$	$F_{2,88} = 6.571$
+ PAH	0.02 (1.29)	-0.55 (1.23)	0.50 (1.08)	$p = .263$	$p = .195$	$p = .002$
	0.21 (1.08)	*-0.12 (1.31)*	*0.49 (1.11)*			
CPT 1						
No PAH	-0.07 (0.92)	0.09 (0.96)	0.94 (0.74)	$F_{1,56} = 1.82$	$F_{1,112} = .969$	$F_{2,112} = 18.18$
+PAH	0.26 (0.48)	0.11 (1.07)	1.31 (0.83)	$p = .183$	$p = .383$	$p <.005$
	0.03 (0.81)	*0.09 (0.99)*	*1.07 (0.78)*			
Math						
No PAH	0.002 (0.79)	0.45 (1.00)	1.43 (1.66)	$F_{1,56} = .820$	$F_{2,112} = 1.91$	$F_{2,112} = 25.057$
+PAH	0.11 (0.59)	0.21 (0.73)	0.91 (0.87)	$p = .369$	$p = .160$	$p <.005$
	0.03 (0.73)	*0.37 (0.93)*	*1.26 (1.46)*			
Match Sample						
No PAH	0.09 (0.59)	-0.08 (0.52)	0.15 (0.61)	$F_{1,56} = 2.61$	$F_{2,112} = .880$	$F_{2,112} = 6.14$
+PAH	0.37 (0.72)	-0.06 (0.50)	0.40 (0.72)	$p = .11$	$p = .413$	$p = .003$
	0.18 (0.64)	*-0.07 (0.51)*	*0.23 (0.65)*			
Sternberg						
No PAH	-0.48 (1.25)	-0.50 (1.27)	0.32 (1.39)	$F_{1,57} = 2.70$	$F_{2,114} = 1.93$	$F_{2,114} = 5.54$
+PAH	0.35 (0.86)	-0.11 (1.36)	0.37 (1.16)	$p = .106$	$p = .150$	$p = .005$
	-0.19 (1.19)	*-0.37 (1.31)*	*0.34 (1.31)*			
SRT 2						
No PAH	0.47 (1.01)	-0.17 (1.53)	0.17 (1.03)	$F_{1,43} = .341$	$F_{2,86} = .185$	$F_{2,86} = 8.56$
+PAH	0.72 (0.65)	-0.11 91.46)	0.41 (0.90)	$p = .562$	$p = .779$	$p <.005$
	0.55 (0.91)	*-0.15 (1.49)*	*0.24 (0.90)*			
CPT 2					$F_{2,108} = 1.21$	$F_{2,108} = 21.06$
No PAH	-0.11 (1.24)	-0.29 (1.11)	0.69 (1.01)	$F_{1,54} = 1.57$	$p = .300$	$p < .005$
+ PAH	0.43 (0.88)	-0.29 (1.38)	1.04 (0.91)	$p = .216$		
	0.70 (1.15)	*-0.29 (1.19)*	*0.81 (0.99)*			

Table 5. Pre-Season Assessment Headache ANAM Throughput Scores Means and Standard Deviations

	Baseline	**Sub-Acute post-injury**	**Prolonged post-injury**	**Group Main Effect**	**Group X Day Interaction**	**Day Main Effect**
SRT 1						
No PAH	239.97 (31.23)	226.79 (50.66)	240.30 (34.31)	$F_{1,49} = 1.14$	$F_{2,98} = .901$	$F_{2,98} = 31.50$
+ PAH	247.85 (39.61)	215.12 (51.82)	247.85 (36.55)	$p = .291$	$p = .403$	$p < .005$
	242.38 (33.78)	*223.21 (50.77)*	*242.61 (34.80)*			
CPT 1						
No PAH	95.75 (23.60)	98.27 (27.16)	122.31 (22.47)	$F_{1,56} = 1.82$	$F_{1,112} = .969$	$F_{2,112} = 18.18$
+PAH	102.89 (13.76)	98.00 (31.20)	133.18 (24.98)	$p = .183$	$p = .383$	$p <.005$
	97.99 (21.14)	*98.19 (28.17)*	*125.72 (23.59)*			
Math						
No PAH	19.48 (5.82)	22.12 (6.83)	29.47 (12.30)	$F_{1,50} = 1.55$	$F_{2,100} = 1.85$	$F_{2,100} = 19.327$
+PAH	19.68 (3.75)	20.09 (5.24)	24.75 (5.27)	$p = .218$	$p = .173$	$p <.005$
	19.54 (5.20)	*21.46 (6.38)*	*27.92 (10.70)*			
Match Sample						
No PAH	39.31 (10.51)	36.99 (11.05)	41.16 (12.41)	$F_{1,49} = 2.61$	$F_{2,98} = 2.12$	$F_{2,98} = 6.68$
+PAH	48.04 (15.63)	36.69 (11.26)	48.01 (15.00)	$p = .052$	$p = .127$	$p = .002$
	42.05 (12.85)	*36.90 (11.01)*	*43.31 (13.51)*			
Sternberg						
No PAH	69.95 (20.38)	69.10 (20.47)	83.57 (24.80)	$F_{1,48} = 1.58$	$F_{2,96} = 1.30$	$F_{2,96} = 5.16$
+PAH	82.84 (16.37)	74.19 (25.62)	84.21 (21.94)	$p = .215$	$p = .277$	$p = .007$
	74.08 (19.96)	*70.73 (22.16)*	*83.77 (23.69)*			
SRT 2						
No PAH	251.52 (32.39)	229.37 (50.95)	240.29 (35.33)	$F_{1,44} = .005$	$F_{2,88} = 2.00$	$F_{2,88} = 13.09$
+PAH	259.18 (25.14)	214.78 (53.76)	249.45 (37.37)	$p = .944$	$p = .152$	$p <.005$
	253.85 (30.44)	*224.93 (51.67)*	*243.07 (35.79)*			
CPT 2						
No PAH	108.57 (24.49)	101.70 (26.66)	121.88 (24.51)	$F_{1,51} = 1.33$	$F_{2,102} = 105$	$F_{2,102} = 19.77$
+ PAH	118.23 (20.31)	101.33 (30.43)	131.73 (20.85)	$p = .255$	$p = .352$	$p < .005$
	111.85 (23.42)	*101.57 (27.7)*	*125.23 (23.61)*			

Table 6. Pre-Season Assessment Headache Number of Previous Concussions per Group (last 7 years)

	0	1	2	3+
NHG (n = 258)	69.0% 177	23.0% 60	7.8% 20	.3% 1
PHG (n=106)	59.5% 63	24.5% 26	9.4% 10	6.6% 7

$\chi^2 = 14.48$ df = 3   p = .002

NHG- negative headache group
PHG- positive headache

Percentages (%) are expressed as a proportion of subjects of each group

Table 7. Posttraumatic Headache Clinical Measures Scores Means and Standard Deviations

	Day 1 post-injury	Day 3 post-injury	Day 7 post -injury	Group Main Effect	Group X Day Interaction	Day Main Effect
Symptom Total						
No PTH	2.32 (3.42)	1.19 (3.94)	.43 (2.21)	$F_{2,229} = 29.75$	$F_{4,458} = 24.98$	$F_{2,458} = 100.21$
Mild PTH	8.07 (8.27)	3.35 (5.43)	.81 (2.06)	$p < .005$	$p <.005$	$p < .005$
Mod-Severe PTH	19.16 (15.23)	10.02 (13.43)	3.32 (8.35)			
	11.88 (13.31)	5.90 (10.40)	1.86 (5.94)			
Symptoms Endorsed						
No PTH	1.53 (2.12)	0.66 (1.76)	0.21 (0.93)	$F_{1,83} = 5.57$	$F_{4,458} = 20.878$	$F_{2,458} = 162.96$
Mild PTH	4.31 (3.41)	2.25 (2.83)	0.58 (1.46)	$p = .019$	$p < .005$	$p < .005$
Mod-Severe PTH	7.28 (3.98)	4.51 (4.58)	1.42 (2.90)			
	5.08 (4.11)	2.94 (3.89)	.88 (2.22)			
SAC Total Score						
No PTH	27.50 (1.75)	27.56 (1.37)	28.25 (1.57)	$F_{2,89} = .283$	$F_{4, 180} = .673$	$F_{2, 180} = 8.46$
Mild PTH	26.44 (2.99)	27.22 (1.72)	27.94 (1.97)	$p = .596$	$p = .596$	$p = .001$
Mod-Severe PTH	26.63 (2.32)	27.46 (2.50)	27.63 (1.58)			
	26.71 (2.53)	27.39 (2.04)	27.86 (1.73)			
BESS Total Score						
No PTH	10.71 (5.23)	9.86 (4.47)	8.86 (3.37)	$F_{2,84} =3.10$	$F_{4,168} = 1.37$	$F_{2,168} = 22.12$
Mild PTH	13.31 (6.15)	10.03 (3.40)	8.06 (5.54)	$p = .05$	$p = .252$	$p < .005$
Mod-Severe PTH	16.02 (7.76)	12.41 (7.27)	10.66 (5.62)			
	14.17 (7.04)	11.13 (6.01)	9.41 (5.38)			

Table 8. Posttraumatic Headache ANAM Z-Scores Means and Standard Deviations

	Sub-acute post-injury	Prolonged post-injury	Group Main Effect	Group X Day Interaction	Day Main Effect
Composite Z					
No PTH	1.60 (5.69)	4.74 (6.33)	$F_{1,41} = .368$	$F_{2,41} = 4.98$	$F_{1,41} = 25.343$
Mild PTH	1.39 (5.24)	3.44 (5.49)	$p = .694$	$p = .012$	$p < .005$
Mod-Severe PTH	-2.23 (6.93)	5.25 (4.80)			
	-0.05 (5.93)	*4.45 (5.34)*			
SRT 1					
No PTH	0.19 (1.56)	0.03 (1.70)	$F_{1,40} = .032$	$F_{2,40} = 3.71$	$F_{1,40} = 3.108$
Mild PTH	0.11 (1.37)	0.30 (0.85)	$p = .969$	$p = .033$	$p = .086$
Mod-Severe PTH	-0.29 (1.22)	0.76 (1.08)			
	-0.06 (1.31)	*0.48 (1.11)*			
CPT 1					
No PTH	0.46 (0.90)	1.07 (0.64)	$F_{1,45} = .072$	$F_{2,45} = 4.41$	$F_{1,45} = 29.80$
Mild PTH	0.45 (0.67)	0.95 (0.60)	$p = .931$	$p = .018$	$p < .005$
Mod-Severe PTH	-0.24 (0.92)	1.34 (0.93)			
	0.24 (0.92)	*1.15 (0.79)*			
Math					
No PTH	0.65 (0.79)	1.12 (1.02)	$F_{1,45} = .298$	$F_{2,45} = .703$	$F_{1,45} = 20.08$
Mild PTH	0.60 (1.13)	1.47 (2.30)	$p = .744$	$p = .500$	$p < .005$
Mod-Severe PTH	0.26 (0.64)	1.26 (0.76)			
	0.46 (0.87)	*1.31 (1.50)*			
Match to Sample					
No PTH	0.12 (0.41)	0.13 (0.57)	$F_{1,45} = .977$	$F_{2,45} = 3.03$	$F_{1,45} = 3.99$
Mild PTH	0.16 (0.48)	0.23 (0.71)	$p = .384$	$p = .058$	$p = .052$
Mod-Severe PTH	-0.27 (0.47)	0.23 (0.72)			
	-0.05 (0.50)	*0.21 (0.67)*			
Sternberg					
No PTH	0.04 (0.78)	0.96 (2.29)	$F_{1,45} = .781$	$F_{2,45} = 1.65$	$F_{1,45} = 9.59$
Mild PTH	0.02 (1.37)	0.17 (1.16)	$p = .464$	$p = .203$	$p = .005$
Mod-Severe PTH	-0.54 (1.37)	0.47 (0.99)			
	-0.23 (1.29)	*0.45 (1.36)*			
SRT 2					
No PTH	0.93 (1.46)	0.12 (1.24)	$F_{1,34} = .255$	$F_{2,34} = .789$	$F_{1,34} = 4.53$
Mild PTH	-0.50 (1.92)	0.14 (1.8)	$p = .777$	$p = .462$	$p = .041$
Mod-Severe PTH	-0.17 (1.19)	0.41 (1.04)			
	-0.25 (1.52)	*0.26 (1.07)*			
CPT 2					
No PTH	0.12 (1.20)	0.90 (0.91)	$F_{1,44} = .259$	$F_{2,44} = 4.21$	$F_{1,44} = 30.10$
Mild PTH	0.10 (0.99)	0.64 (1.00)	$p = .773$	$p = .021$	$p < .005$
Mod-Severe PTH	-0.52 (1.31)	1.02 (0.94)			
	-0.17 (1.20)	*0.86 (0.96)*			

Table 9. Posttraumatic Headache ANAM Throughput Scores Means and Standard Deviations

	Sub-acute post-injury	Prolonged post-injury	Group Main Effect	Group X Day Interaction	Day Main Effect
SRT 1					
No PTH	241.43 (47.59)	235.94 (51.85)	$F_{1,40}$= .029	$F_{2,40}$= 3.36	$F_{1,40}$= 3.59
Mild PTH	233.99 (47.46)	243.14 (26.95)	p = .969	p = .045	p = .065
Mod-Severe PTH	224.63 (39.70)	257.75 (36.49)			
	230.63 (43.20)	*249.10 (36.60)*			
CPT 1					
No PTH	112.36 (27.65)	130.31 (16.15)	$F_{1,41}$ = .324	$F_{2,41}$= 3.89	$F_{1,41}$ = 23.11
Mild PTH	109.46 (19.19)	122.43 (17.75)	p = .725	p = .028	p <.005
Mod-Severe PTH	95.39 (28.87)	133.78 (26.63)			
	103.21 (29.09)	*129.10 (22.44)*			
Math					
No PTH	24.48 (5.86)	27.35 (7.95)	$F_{1,42}$ = .188	$F_{2,42}$= .928	$F_{1,42}$= 18.19
Mild PTH	22.82 (7.87)	29.61 (17.09)	p = .829	p = .403	p <.005
Mod-Severe PTH	20.88 (4.64)	28.39 (5.63)			
	22.21 (6.19)	*28.64 (11.17)*			
Match to Sample					
No PTH	41.83 (8.81)	42.76 (11.67)	$F_{1,42}$= .583	$F_{2,42=}$ 3.19	$F_{1,42}$= 3.84
Mild PTH	41.54 (10.18)	42.36 (14.12)	p = .562	p = .051	p = .057
Mod-Severe PTH	33.34 (10.21)	44.22 (14.71)			
	37.77 (10.61)	*43.30 (13.74)*			
Sternberg					
No PTH	77.46 (15.54)	99.65 (41.89)	$F_{1,39}$= 1.35	$F_{2,39}$ = 3.67	$F_{1,39}$ = 10.76
Mild PTH	82.47 (15.73)	81.52 (20.19)	p = .270	p = .035	p = .002
Mod-Severe PTH	66.09 (23.94)	85.71 (17.29)			
	73.84 (21.08)	*86.54 (23.95)*			
SRT 2					
No PTH	239.99 (43.41)	236.60 (41.29)	F_{138} = .082	F_{238}= 6.06	$F_{1,38}$ = 5.60
Mild PTH	230.42 (38.81)	235.01 (37.70)	p = .922	p = .005	p = .023
Mod-Severe PTH	210.10 (55.65)	253..57 (35.05)			
	223.86 (48.08)	*243.02 (37.37)*			
CPT 2					
No PTH	111.85 (26.55)	130.29 (19.87)	$F_{1,42}$= .259	$F_{2,42}$= 4.64	$F_{1,42}$= 27.75
Mild PTH	111.46 (22.16)	121.72 (22.72)	p = .758	p = .015	p < .005
Mod-Severe PTH	97.64 (27.96)	131.86 (21.13)			
	105.08 (26.16)	*127.83 (21.59)*			

Table 10. Posttraumatic Headache Number of Previous Concussions per Group (last 7 years)

	0	1	2	3+
No-HA (n = 64)	44 68.8%	17 26.6%	3 4.6%	0 0%
Mild PTH (n = 102)	69 67.6%	23 22.6%	7 6.9%	3 2.9%
Mod-Severe PTH (n = 121)	77 63.6%	27 22.4%	12 9.9%	5 4.1%

$\chi^2 = 4.79$ df = 6 p = .572

No-HA – No Posttraumatic Headache group
Mild PTH – Mild Posttraumatic Headache group
Mod-Severe – Moderate to Severe Posttraumatic Headache group

Percentages (%) are expressed as a proportion of subjects of each group

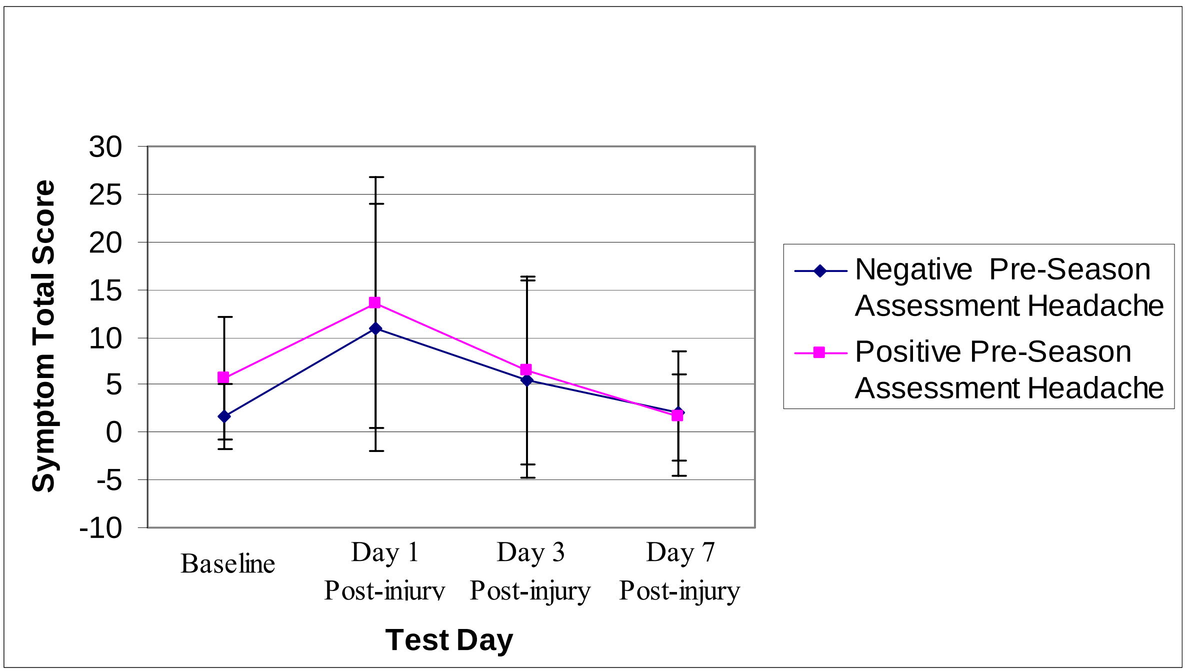

Figure 1. PAH Symptom Total Score

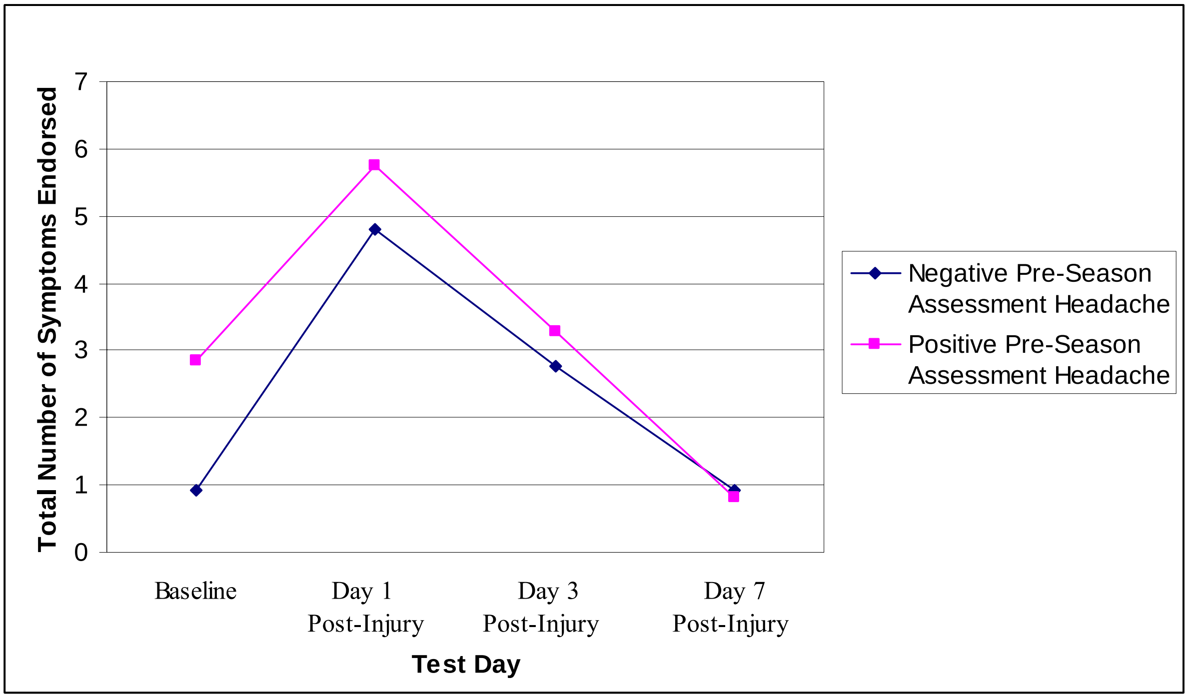

Figure 2. PAH Total Number of Symptoms Endorsed

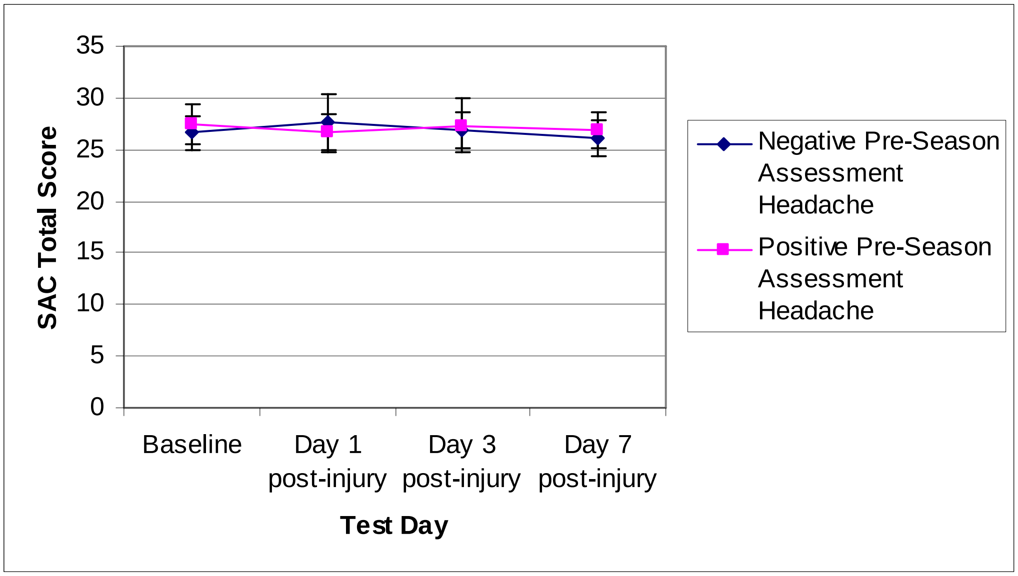

Figure 3. PAH SAC Total Score

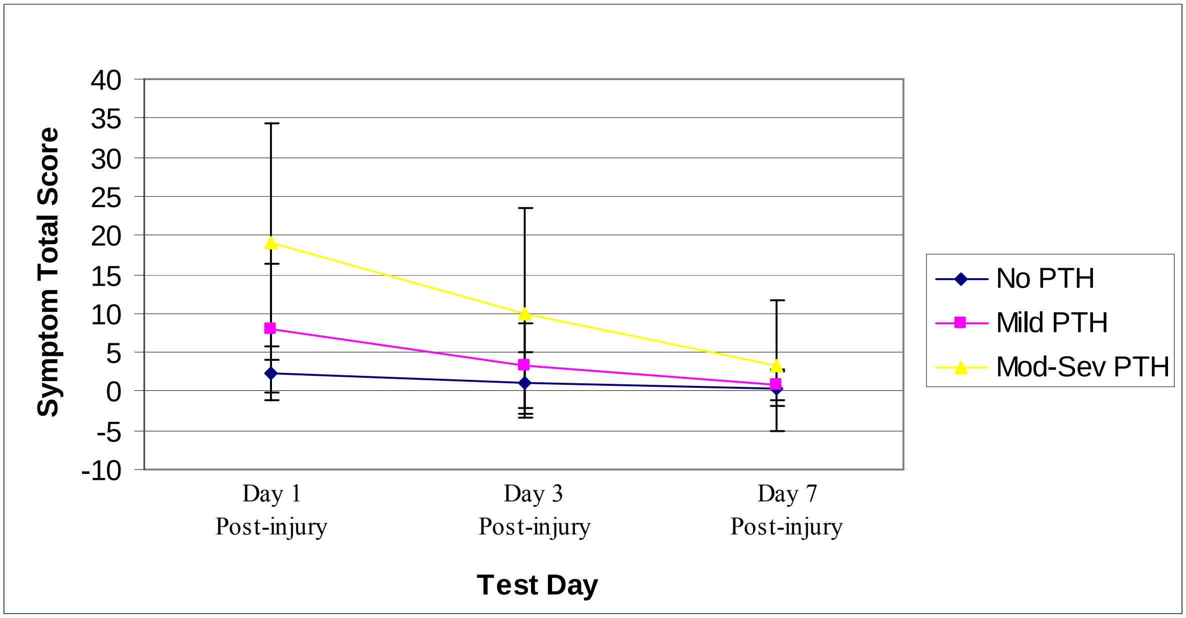

Figure 4. PTH Symptom Total Score

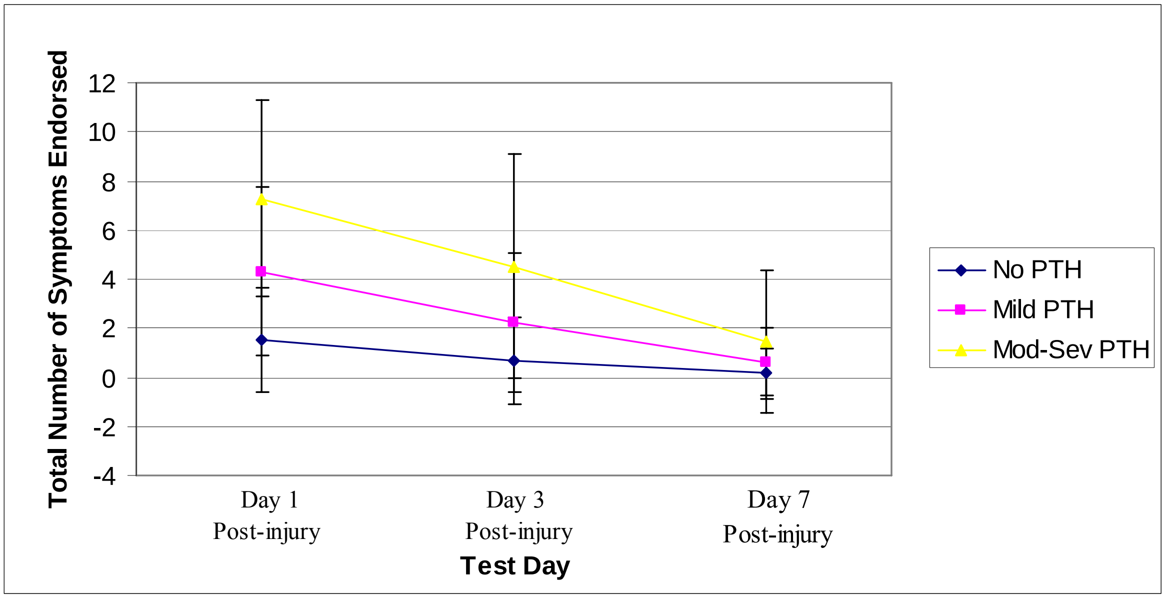

Figure 5. PTH Total Number of Symptoms Endorsed

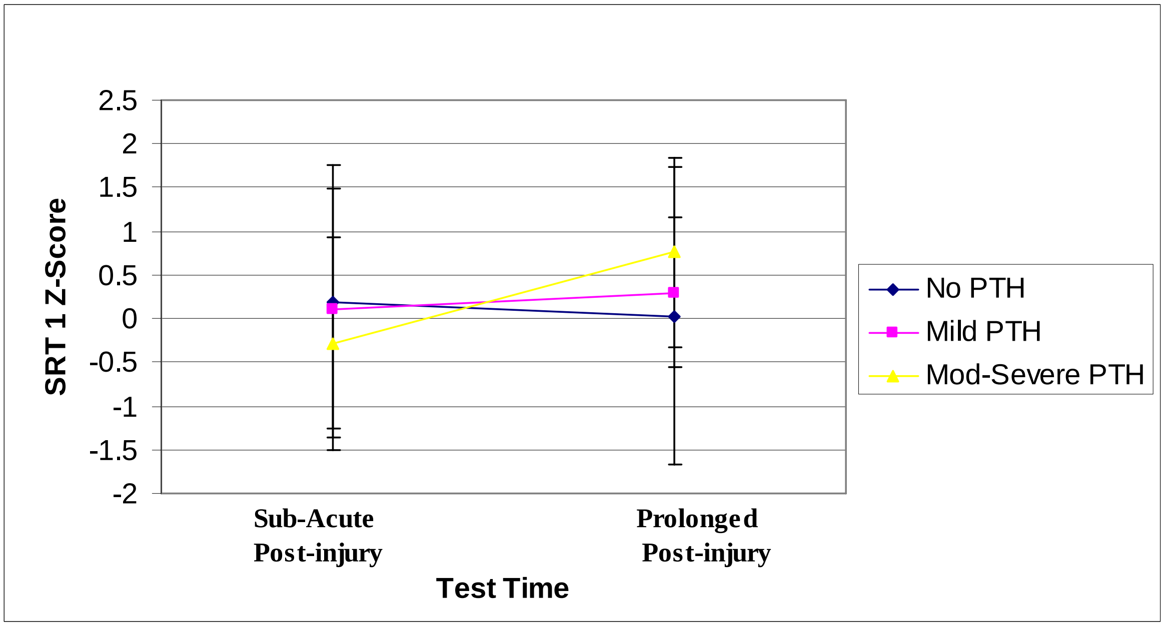

Figure 6. PTH SRT 1 Z-Score

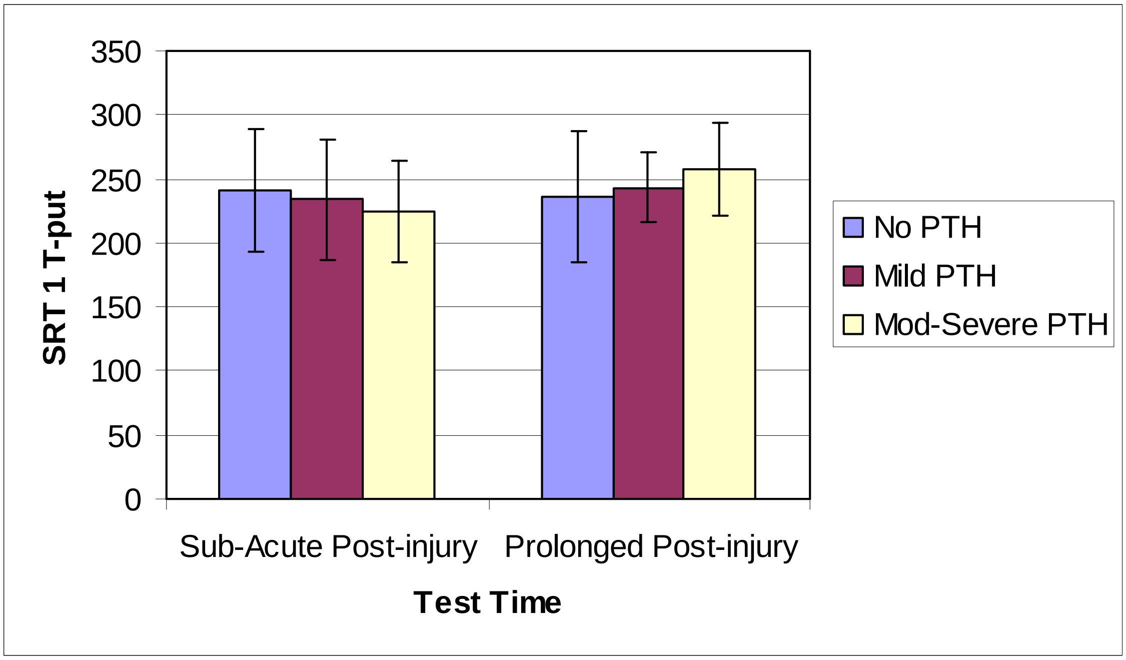

Figure 7. PTH SRT 1 Throughput Score

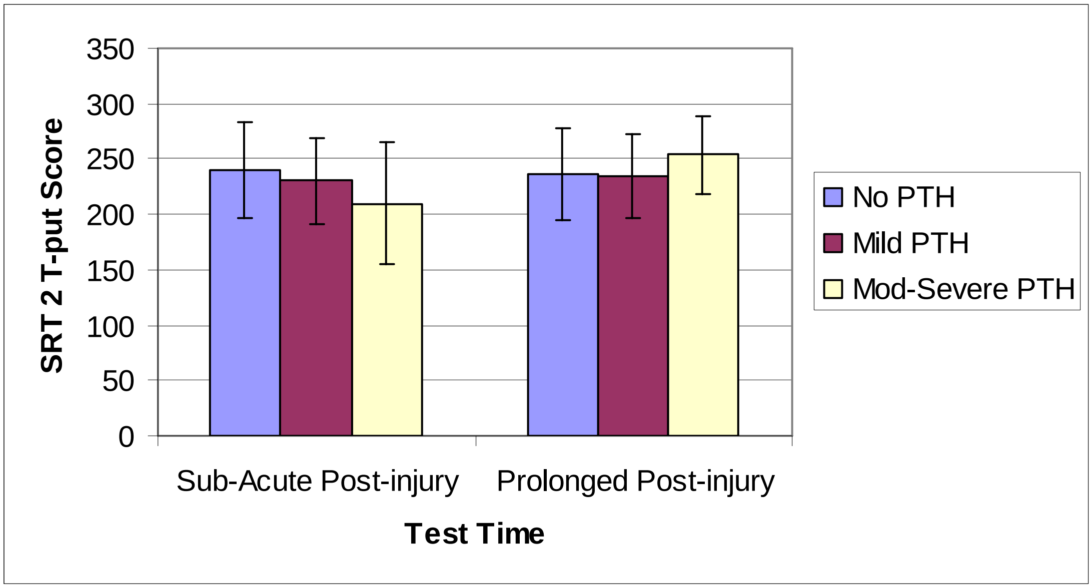

Figure 8. PTH SRT 2 Throughput Score

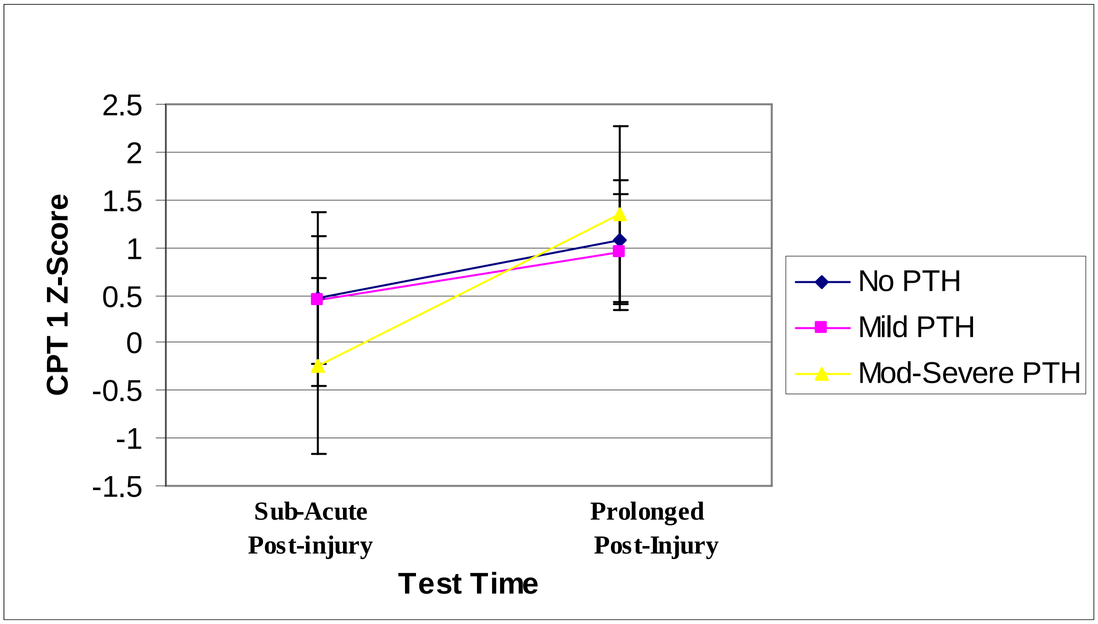

Figure 9. PTH CPT 1 Z-Score

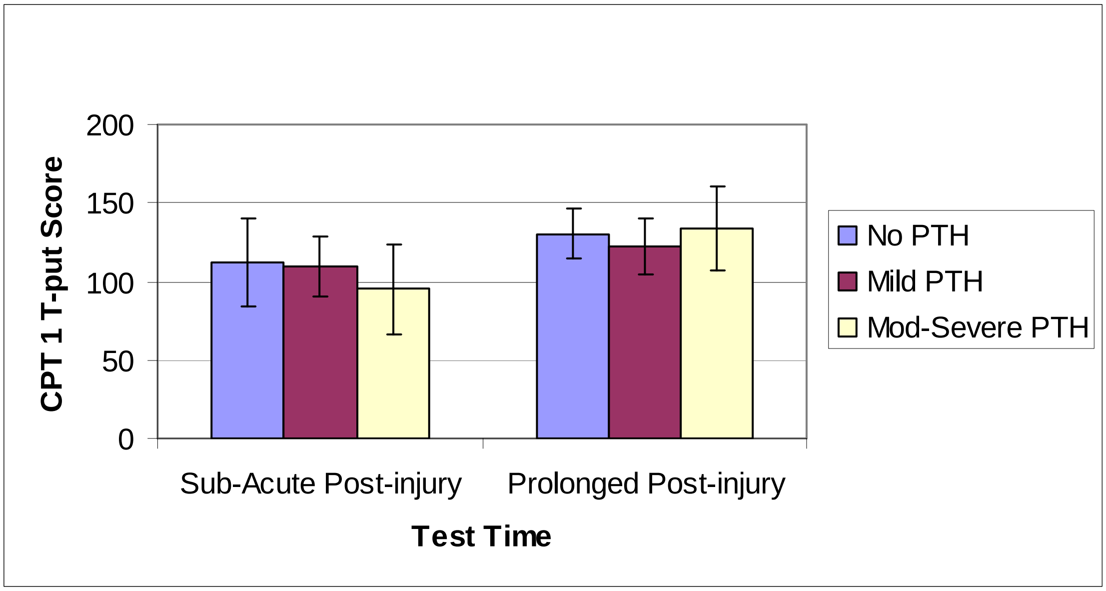

Figure 10. PTH CPT 1 Throughput Score

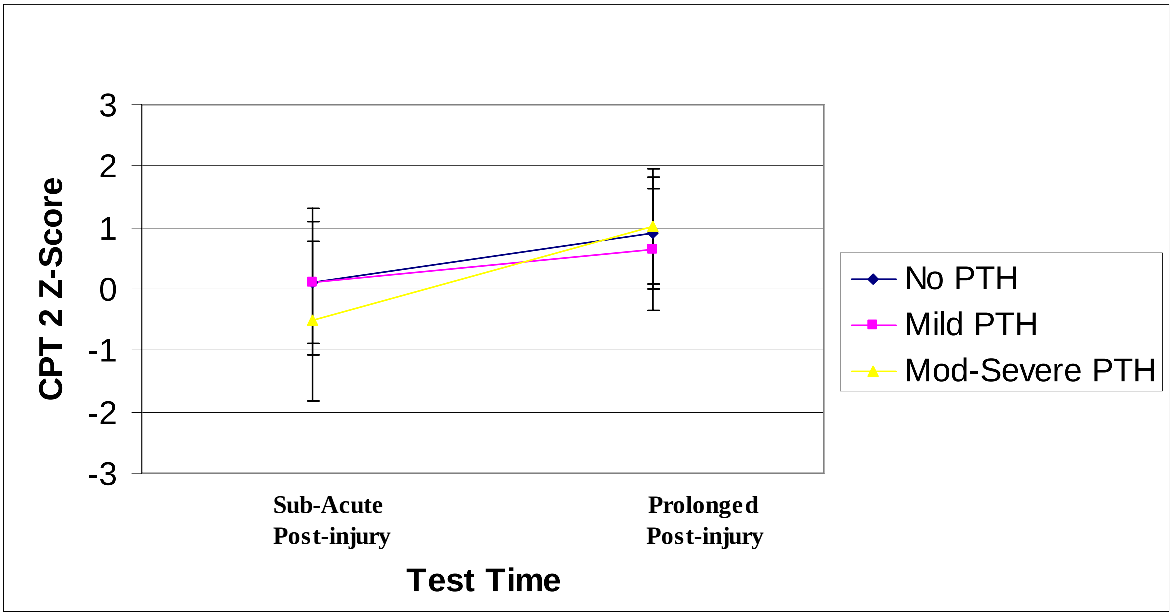

Figure 11. PTH CPT 2 Z-Score

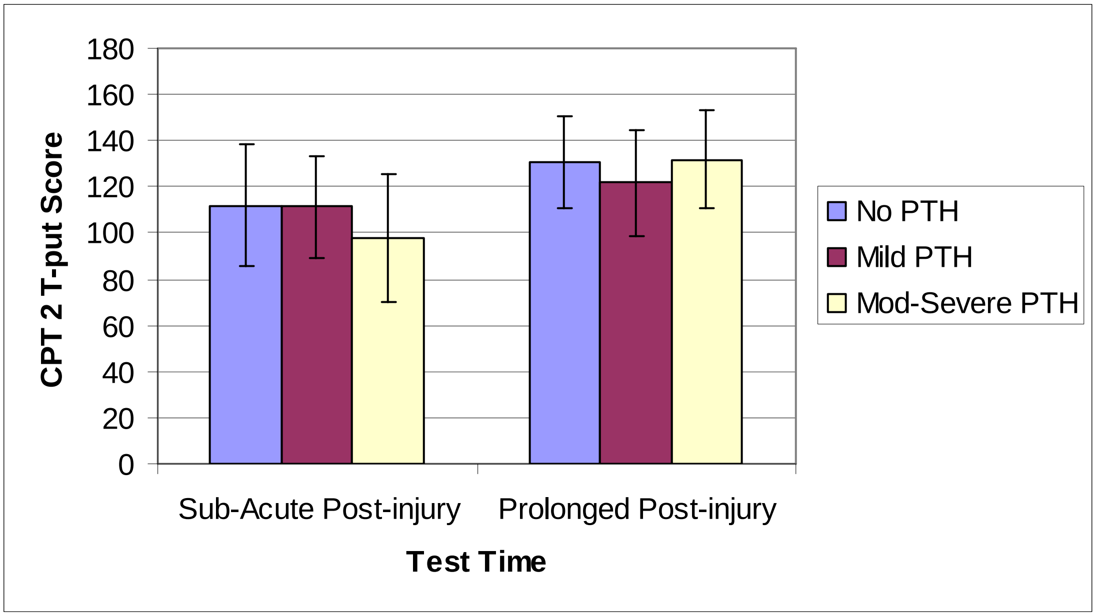

Figure 12. PTH CPT 2 Throughput Score

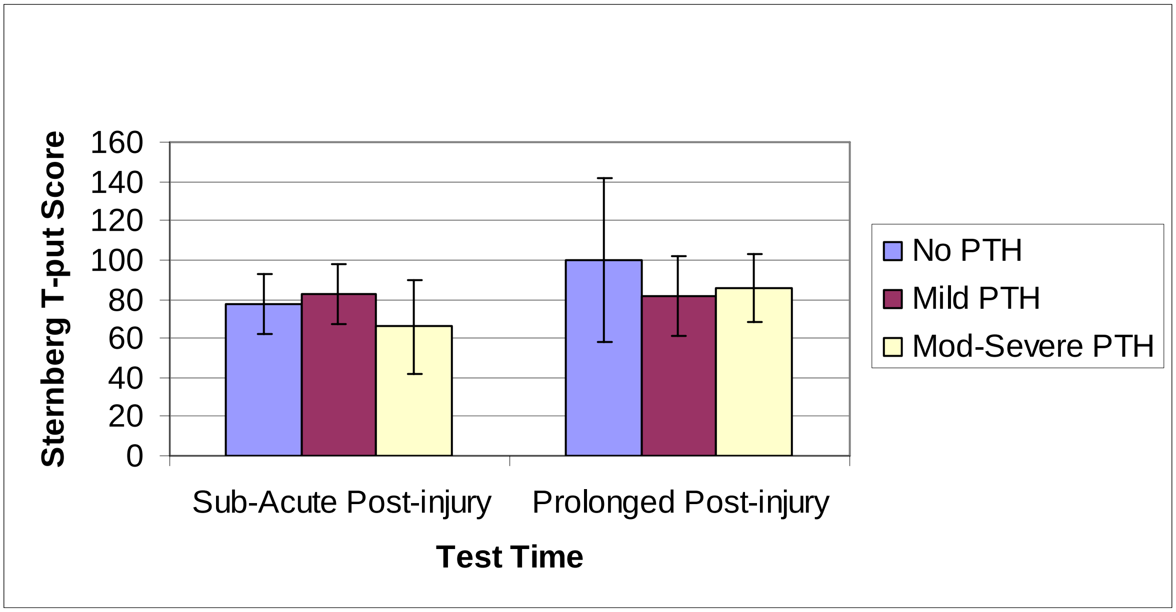

Figure 13. PTH Sternberg Throughput Score

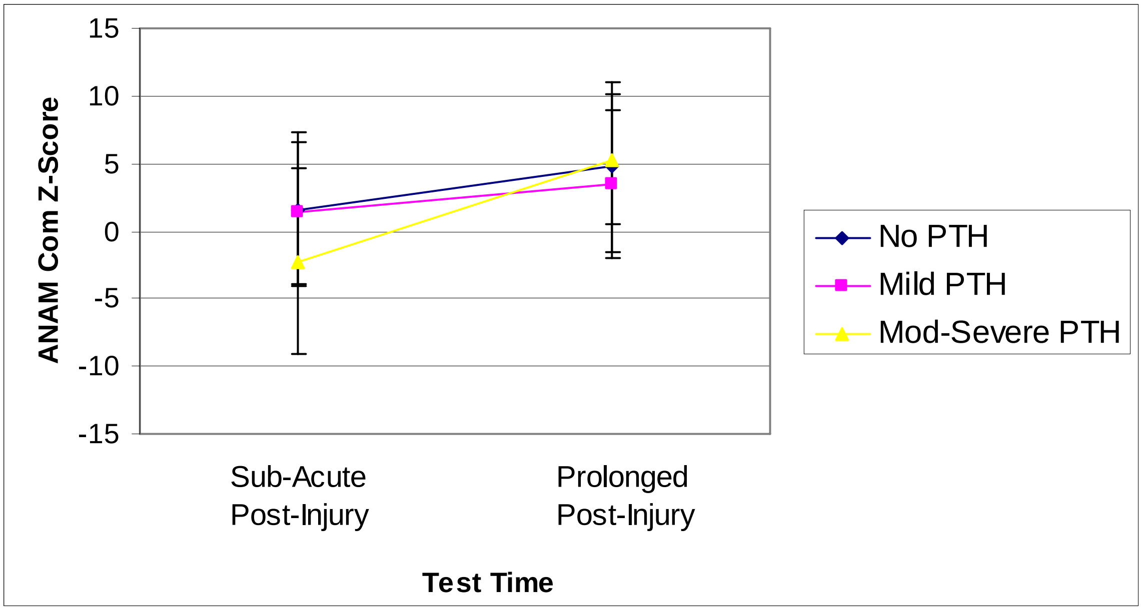

Figure 14. PTH ANAM Composite Z-Score

CHAPTER V

DISCUSSION

Although studies have continued to examine common clinical measures of concussion, few have examined the effect of headache on these measures. Current studies suggest HA may affect an individual's ability to perform normally on neurocognitive tasks.(Collins et al., 2003; Gilkey, Ramadan, Aurora, & Welch, 1997; Hooker, 1986; Mihalik et al., 2005) The primary purpose of this study was two fold. One specific goal of the study was to examine the effects of headache, both pre-season assessment headache (PAH) and posttraumatic headache (PTH) on clinical measures of neuropsychological performance and postural stability. Our second aim was to examine the association of concussion and headache. Current literature discusses the effects of PTH and posttraumatic migraine (PTM) on measures similar to those used in our study. These studies report an increase in symptoms as well as deficits in neuropsychological test scores in individuals reporting PTH at day 1 post-injury.(Collins et al., 2003; Mihalik et al., 2005) Our study was consistent with these findings in that individuals reporting PTH as well as PAH recovered significantly different from individuals with no headache.

Pre-Season Assessment Headache

The first portion of our study examined the effects of PAH (HA reported at baseline) on symptoms, ANAM, the SAC, the BESS, and a GSC. To our knowledge few, if any studies have examined the effects of headache in healthy athletes on clinical measures of concussion. As our study may be one of the first, it suggests that individuals presenting with headache upon baseline testing may display an increase in other symptoms as well as an increase in the intensity of these symptoms. (Table 3; Figure 1) This is important to clinicians as they should note if the athlete presented with a headache at baseline as it could affect the overall symptom total score. The SAC yielded a significant group x day interaction leading to the suggestion that the effect of the test score on a given day depended upon the headache classification of the athlete. In regards to neuropsychological testing, there were no significant differences found between the groups or any group by day interactions suggesting that headache at baseline may have little effect on this type of neuropsychological testing battery. A main effect of day was found regarding all modules of ANAM using both the Z-scores and the throughput scores; whereby, individuals performed significantly worse on day 1 post-injury but began to improve by day 3 post-injury. This is consistent with the literature as deficits appear post-injury and begin to resolve as time elapses. As a result of practice effects, individuals often improve on the tests by day seven. (McCrea et al., 2003) Another important finding of this study was the significant association between previous history of concussions and whether or not headache was reported at baseline. Individuals suffering from three or more concussion were more likely to report headache at baseline than individuals with a history of less than three. (Table 6) This finding is consistent with current literature suggesting that after three or more concussions long term repercussions may be present. (Guskiewicz et al., 2005; Guskiewicz et al., 2003) The association also provides further information as to why individuals experiencing headache at baseline display an increase in symptoms as well as a slower symptomatic recovery.

Posttraumatic Headache

The second part of our study focused these same measures in relation to PTH. We found that individuals reporting PTH reported an increased number of symptoms and a greater intensity of symptoms than individuals not reporting headache. This finding was magnified in individuals reporting moderate-severe PTH suggesting that headache severity may indicate other levels of neurocognitive deficits. (Table 7; Figure 4) We also found that both the Z-scores and throughput scores of CPT 1 and CPT 2, SRT 1 and SRT 2 displayed significant interactions. The STN and SRT 2 throughput scores also yielded significant interactions. (Tables 8-9, Figures6-14) These findings suggest that the effects testing concentration, working memory, and reaction time are dependent upon the headache classification of the athlete and presence of concussion. Headache appears to affect these measures by causing the athlete to experience and report increased neurocognitive deficits.

Headache, Concussion, and Pain

Current literature suggests pain, including headache effects concentration, mental processing, and reaction time. Our study reinforces thesis findings as PTH significantly affected mental processing (CPT 1 and 2) as well the reaction time measures (SRT 1 and 2). In our study the PAH group did not display significant deficits compared to the No-headache group. This finding reinforces current literature suggesting that PTH is a sign of incomplete recovery and other neurocognitive deficits. (Collins et al., 2003) As headache often preceeds many other postconcussive symptoms, the neurocognitive and other aspects of postconcussion syndrome, may be at least in part the result of the headache. (Hooker, 1986) Studies have found evidence of neuropsychological impairment in cases of PTH; however, there are no studies we have found discriminating between possible sources of this impairment. Many confounding factors ranging from pain, the actual brain injury or other causes may contribute to neuropsychological impairment. In our study, we found significant interactions between PTH and neuropsychological measures with no main effect of headache group, and no significant interactions for these measures regarding PAH suggesting that these findings are a combination of the headache and the concussion. Headache, concussion, and general pain may alter cerebral blood flow as well as affect depolarization of neurons, alter excitatory amino acids, nitric oxide, neuropeptides, glucose, magnesium/calcium, and neurotransmitters such as nonepinephrine and serotonin. (Gilkey, Ramadan, Aurora, & Welch, 1997; Packard RC, 1997).

Limitations

Although our study yielded important clinical findings, it did present with limitations. The number of males in our study greatly outnumbered the females, which may have lead to skewed data, especially in relation to headache as in general, females are more likely to experience headache. We also only used information out to day 7 post-injury. Although many concussions have resolved by this point, many to do not completely resolve until day 10 post-injury or beyond. Various trained athletic trainers also conducted the testing at different testing sites, which may have lead to some variability in testing procedures and timing. The greatest limitation to our study was the small subset of individuals who completed the ANAM testing battery at all dates included in the study. This lead to a small sample size, decreased power, and an unbalanced design which in some cases may have been a hindrance to identifying statistical significance in some cases. Although these limitations were present we believe our study provides valuable clinical information regarding headache and clinical measures of concussion.

Clinical Implications

Headache is common in the physically active population indicating the need for a more clear understanding of its effects on commonly used clinical measures of concussion. Our study found that individuals suffering from headache at baseline as well as individuals reporting headache at day 1 post-injury displayed an increased number of symptoms and an increase in intensity of symptoms throughout all of the test days, which reinforces the case for the athlete to be completely asymptomatic before return and the case for obtaining baseline and serial scores. Our findings support current literature suggesting that headache is a sign of incomplete recovery. Our study only evaluated these effects through post-injury day 7 and previous literature has only studied through day 10. Future research should investigate these effects further from post-injury as well as the effects of headache in a healthy physically active population. Future studies should include both asymptomatic (no HA) and symptomatic (HA) test sessions to truly isolate the effects of headache on these clinical measures. Lastly, our study reinforces the findings of McCrea et al (2005) implicating that neuropsychological testing should be used as a more sensitive measure after complete symptom resolution, as an athlete would not return if symptomatic regardless of neuropsychological test scores. If the athlete were asymptomatic, the neuropsychological test results would provide clinicians with more valuable information. Our reasoning behind using sub-acute and prolonged regarding ANAM was based on these findings.

Conclusions

As clinicians, we should be mindful of the presence of headache in both our healthy and unhealthy athletes as headache may affect many aspects of neurocognition. We should be especially mindful of headache in concussed athletes as it is a sign of incomplete recovery and other possible neurological deficits.

Appendix A Graded Symptom Checklist

Name: ________________________ **ID#:** _____________ **Date:** ___________ **Pre-test** **Post-test**

Height: __________ ***Weight:*** ___________ ***Phone #:*** ________________

Examiner:________________________________ **Session: 1 or 2** **No-HA** **HA** **C1 or C2**

Symptom Scale

Only score items that you are currently experiencing

Symptom	***None***	**Mild**		**Moderate**		**Severe**	
1. HEADACHE	**0**	**1**	**2**	**3**	**4**	**5**	**6**
2. NAUSEA	**0**	**1**	**2**	**3**	**4**	**5**	**6**
3. VOMITING	**0**	**1**	**2**	**3**	**4**	**5**	**6**
4. BALANCE	**0**	**1**	**2**	**3**	**4**	**5**	**6**
PROBLEMS/DIZZINESS	**0**	**1**	**2**	**3**	**4**	**5**	**6**
5. FATIGUE	**0**	**1**	**2**	**3**	**4**	**5**	**6**
6. SKIN RASH/ITCHING	**0**	**1**	**2**	**3**	**4**	**5**	**6**
7. TROUBLE SLEEPING	**0**	**1**	**2**	**3**	**4**	**5**	**6**
8. SLEEPING MORE THAN USUAL	**0**	**1**	**2**	**3**	**4**	**5**	**6**
9. DROWSINESS	**0**	**1**	**2**	**3**	**4**	**5**	**6**
10. SENSITIVITY TO LIGHT	**0**	**1**	**2**	**3**	**4**	**5**	**6**
11. BLURRED VISION	**0**	**1**	**2**	**3**	**4**	**5**	**6**
12. SENSITIVITY TO NOISE	**0**	**1**	**2**	**3**	**4**	**5**	**6**
13. JOINT STIFFNESS	**0**	**1**	**2**	**3**	**4**	**5**	**6**
(**E.G.**FINGERS)	**0**	**1**	**2**	**3**	**4**	**5**	**6**
14. SADNESS	**0**	**1**	**2**	**3**	**4**	**5**	**6**
15. IRRITABILITY	**0**	**1**	**2**	**3**	**4**	**5**	**6**
16. NUMBNESS/TINGLING	**0**	**1**	**2**	**3**	**4**	**5**	**6**
17. FEELING LIKE "IN A FOG"	**0**	**1**	**2**	**3**	**4**	**5**	**6**
18. DIFFICULTY CONCENTRATING	**0**	**1**	**2**	**3**	**4**	**5**	**6**
19. DIFFICULTY REMEMBERING							
20. NECK PAIN							
Column Total Score *(sum values not including #6 and #13)*	**0**						

Total # of Items Endorsed *(not including #6 & #13)*	
OVERALL TOTAL SCORE (not including #6 & #13)	

Appendix B ANAM Test Modules

Test Module	Cognitive Processes Measures
Simple Reaction Time	Reaction time
Match to Sample	Visual memory
Continuous Performance	Concentration
	Working memory
Math Processing	Mental processing speed
	Mental efficiency
Sternberg Memory Search	Working memory

Appendix C Standardized Assessment of Concussion (A)

NAME:______________________________

TEAM: ______ **EXAMINER:**__________________________**Date of Exam**: ______**Time:**

INTRODUCTION:

I am going to ask you some questions.
Please listen carefully and give your best effort.

ORIENTATION

What Month is it?___________________0 1
What's the Date today?______________0 1
What's the Day of Week?____________0 1
What Year is it?____________________0 1
What Time is it right now? (within 1 hr.)__________0 1

Award 1 point for each correct answer.

ORIENTATION TOTAL SCORE ☐

IMMEDIATE MEMORY

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order.

LIST	TRIAL 1	TRIAL 2	TRIAL 3
ELBOW	0 1	0 1	0 1
APPLE	0 1	0 1	0 1
CARPET	0 1	0 1	0 1
SADDLE	0 1	0 1	0 1
BUBBLE	0 1	0 1	0 1
TOTAL			

Trials 2 & 3: **I am going to repeat that list again. Repeat back as many words as you can remember in any order, even if you said the word before.**

Complete all 3 trials regardless of score on trial 1 & 2. 1 pt. for each correct response. Total score equals sum across all 3 trials.
Do not inform the subject that delayed recall will be tested.

IMMEDIATE MEMORY TOTAL SCORE ☐

EXERTIONAL MANEUVERS:

If subject is not displaying or reporting symptoms, conduct the following maneuvers to create conditions under which symptoms likely to be elicited and detected. These measures need not be conducted if a subject is already displaying or reporting any symptoms. If not conducted, allow 2 minutes to keep time delay constant before testing Delayed Recall. These methods should be administered for baseline testing of normal subjects.

NEUROLOGIC SCREENING

LOSS OF CONSCIOUSNESS/ WITNESSED UNRESPONSIVENESS	☐ No ☐ Yes Length:
POST-TRAUMATIC AMNESIA? Poor recall of events after injury	☐ No ☐ Yes Length:
RETROGRADE AMNESIA? Poor recall of events before injury	☐ No ☐ Yes Length:

	NORMAL	ABNORMAL
STRENGTH -		
Right Upper Extremity	☐	☐
Left Upper Extremity	☐	☐
Right Lower Extremity	☐	☐
Left Lower Extremity	☐	☐
SENSATION - examples: FINGER-TO-NOSE/ROMBERG	☐	☐
COORDINATION - examples: TANDEM WALK/ FINGER-NOSE-FINGER	☐	☐

CONCENTRATION

Digits Backward: **I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.**
If correct, go to next string length. If incorrect, read trial 2. 1 pt. possible for each string length. Stop after incorrect on both trials.

4-9-3	**6-2-9**	0 1
3-8-1-4	**3-2-7-9**	0 1
6-2-9-7-1	**1-5-2-8-6**	0 1
7-1-8-4-6-2	**5-3-9-1-4-8**	0 1

Months in Reverse Order: **Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November...Go ahead.** 1 pt. for entire sequence correct.

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan 0 1

CONCENTRATION TOTAL SCORE ☐

DELAYED RECALL

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order. Circle each word correctly recalled. Total score equals number of words recalled.

ELBOW APPLE CARPET SADDLE BUBBLE

DELAYED RECALL TOTAL SCORE ☐

SAC SCORING SUMMARY

Exertional Maneuvers & Neurologic Screening are important for examination, but <u>not</u> incorporated into SAC Total Score.

ORIENTATION	**/ 5**
IMMEDIATE MEMORY	**/ 15**
CONCENTRATION	**/ 5**
DELAYED RECALL	**/ 5**
SAC TOTAL SCORE	**/30**

Appendix D Balance Error Scoring System (Guskiewicz)

Balance Error Scoring System – Types of Errors
1. Hands lifted off iliac crest 2. Opening eyes 3. Step, stumble, or fall 4. Moving hip into > 30 degrees abduction 5. Lifting forefoot or heel 6. Remaining out of test position >5 sec
The BESS is calculated by adding one error point for each error during the 6 20-second tests.

Which **foot** was tested: ☐ Left ☐ Right
(i.e. which is the **non-dominant** foot)

SCORE CARD: (# errors)	***FIRM Surface***	***FOAM Surface***
Double Leg Stance (feet together)		
Single Leg Stance (non-dominant foot)		
Tandem Stance (non-dom foot in back)		
Total Scores:		
BESS TOTAL:		

Appendix E SPSS Output

PAH Symptoms Endorsed

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
testday	Sphericity Assumed	1960.832	3	653.611	108.947	.000	.326
	Greenhouse-Geisser	1960.832	2.186	897.156	108.947	.000	.326
	Huynh-Feldt	1960.832	2.218	884.178	108.947	.000	.326
	Lower-bound	1960.832	1.000	1960.832	108.947	.000	.326
testday * blhagrp	Sphericity Assumed	101.282	3	33.761	5.627	.001	.024
	Greenhouse-Geisser	101.282	2.186	46.340	5.627	.003	.024
	Huynh-Feldt	101.282	2.218	45.670	5.627	.003	.024
	Lower-bound	101.282	1.000	101.282	5.627	.019	.024
Error(testday)	Sphericity Assumed	4049.575	675	5.999			
	Greenhouse-Geisser	4049.575	491.762	8.235			
	Huynh-Feldt	4049.575	498.980	8.116			
	Lower-bound	4049.575	225.000	17.998			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	5577.025	1	5577.025	247.330	.000	.524
blhagrp	125.545	1	125.545	5.568	.019	.024
Error	5073.510	225	22.549			

PTH Symptoms Endorsed

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
testday	Sphericity Assumed	1378.193	2	689.097	162.963	.000	.416
	Greenhouse-Geisser	1378.193	1.940	710.460	162.963	.000	.416
	Huynh-Feldt	1378.193	1.973	698.437	162.963	.000	.416
	Lower-bound	1378.193	1.000	1378.193	162.963	.000	.416
testday * pthgrp	Sphericity Assumed	353.142	4	88.286	20.878	.000	.154
	Greenhouse-Geisser	353.142	3.880	91.023	20.878	.000	.154
	Huynh-Feldt	353.142	3.947	89.482	20.878	.000	.154
	Lower-bound	353.142	2.000	176.571	20.878	.000	.154
Error(testday)	Sphericity Assumed	1936.677	458	4.229			
	Greenhouse-Geisser	1936.677	444.228	4.360			
	Huynh-Feldt	1936.677	451.875	4.286			
	Lower-bound	1936.677	229.000	8.457			

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Intercept	3993.993	1	3993.993	187.953	.000	.451
pthgrp	1392.392	2	696.196	32.762	.000	.222
Error	4866.246	229	21.250			

Post Hoc Tests

PTH groups

Multiple Comparisons

Measure: MEASURE_1
Tukey HSD

(I) PTH groups	(J) PTH groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
No PTH group	Mild PTH group	-1.5772*	.48801	.004	-2.7284	-.4259
	Mod-Sev PTH group	-3.6056*	.46778	.000	-4.7092	-2.5021
Mild PTH group	No PTH group	1.5772*	.48801	.004	.4259	2.7284
	Mod-Sev PTH group	-2.0285*	.39441	.000	-2.9589	-1.0980
Mod-Sev PTH group	No PTH group	3.6056*	.46778	.000	2.5021	4.7092
	Mild PTH group	2.0285*	.39441	.000	1.0980	2.9589

Based on observed means.

*. The mean difference is significant at the .05 level.

PAH Symptom Total Score

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testday	Sphericity Assumed	11418.438	3	3806.146	77.756	.000	.257	233.269	1.000
	Greenhouse-Geisser	11418.438	2.025	5638.726	77.756	.000	.257	157.457	1.000
	Huynh-Feldt	11418.438	2.053	5562.948	77.756	.000	.257	159.601	1.000
	Lower-bound	11418.438	1.000	11418.438	77.756	.000	.257	77.756	1.000
testday * blhagrp	Sphericity Assumed	501.293	3	167.098	3.414	.017	.015	10.241	.769
	Greenhouse-Geisser	501.293	2.025	247.552	3.414	.033	.015	6.913	.645
	Huynh-Feldt	501.293	2.053	244.225	3.414	.033	.015	7.007	.649
	Lower-bound	501.293	1.000	501.293	3.414	.066	.015	3.414	.452
Error(testday)	Sphericity Assumed	33041.079	675	48.950					
	Greenhouse-Geisser	33041.079	455.626	72.518					
	Huynh-Feldt	33041.079	461.832	71.543					
	Lower-bound	33041.079	225.000	146.849					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	25543.552	1	25543.552	139.026	.000	.382	139.026	1.000
blhagrp	583.358	1	583.358	3.175	.076	.014	3.175	.426
Error	41339.609	225	183.732					

a. Computed using alpha = .05

PTH Symptom Total Score

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
day	Sphericity Assumed	7323.361	2	3661.681	100.214	.000	.304	200.428	1.000
	Greenhouse-Geisser	7323.361	1.830	4001.169	100.214	.000	.304	183.422	1.000
	Huynh-Feldt	7323.361	1.860	3936.404	100.214	.000	.304	186.440	1.000
	Lower-bound	7323.361	1.000	7323.361	100.214	.000	.304	100.214	1.000
day * pthgrp	Sphericity Assumed	3650.446	4	912.612	24.977	.000	.179	99.907	1.000
	Greenhouse-Geisser	3650.446	3.661	997.223	24.977	.000	.179	91.430	1.000
	Huynh-Feldt	3650.446	3.721	981.082	24.977	.000	.179	92.934	1.000
	Lower-bound	3650.446	2.000	1825.223	24.977	.000	.179	49.953	1.000
Error(day)	Sphericity Assumed	16734.672	458	36.539					
	Greenhouse-Geisser	16734.672	419.140	39.926					
	Huynh-Feldt	16734.672	426.036	39.280					
	Lower-bound	16734.672	229.000	73.077					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	18262.172	1	18262.172	98.080	.000	.300	98.080	1.000
pthgrp	11077.411	2	5538.706	29.746	.000	.206	59.493	1.000
Error	42639.117	229	186.197					

a. Computed using alpha = .05

Post Hoc Tests
PTH groups

Multiple Comparisons

Measure: MEASURE_1
Tukey HSD

(I) PTH groups	(J) PTH groups	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
No PTH group	Mild PTH group	-2.7661	1.44457	.137	-6.1740	.6417
	Mod-Sev PTH group	-9.5213*	1.38468	.000	-12.7878	-6.2547
Mild PTH group	No PTH group	2.7661	1.44457	.137	-.6417	6.1740
	Mod-Sev PTH group	-6.7551*	1.16749	.000	-9.5093	-4.0010
Mod-Sev PTH group	No PTH group	9.5213*	1.38468	.000	6.2547	12.7878
	Mild PTH group	6.7551*	1.16749	.000	4.0010	9.5093

Based on observed means.

*. The mean difference is significant at the .05 level.

PAH ANAM Com-Z

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	520.720	2	260.360	15.372	.000	.243	30.745	.999
	Greenhouse-Geisser	520.720	1.819	286.345	15.372	.000	.243	27.955	.998
	Huynh-Feldt	520.720	1.926	270.425	15.372	.000	.243	29.600	.999
	Lower-bound	520.720	1.000	520.720	15.372	.000	.243	15.372	.970
testtime * BLHA_grp	Sphericity Assumed	80.497	2	40.249	2.376	.098	.047	4.753	.470
	Greenhouse-Geisser	80.497	1.819	44.266	2.376	.104	.047	4.321	.446
	Huynh-Feldt	80.497	1.926	41.805	2.376	.101	.047	4.576	.460
	Lower-bound	80.497	1.000	80.497	2.376	.130	.047	2.376	.327
Error(testtime)	Sphericity Assumed	1625.941	96	16.937					
	Greenhouse-Geisser	1625.941	87.288	18.627					
	Huynh-Feldt	1625.941	92.427	17.592					
	Lower-bound	1625.941	48.000	33.874					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	295.241	1	295.241	6.005	.018	.111	6.005	.670
BLHA_grp	1.197	1	1.197	.024	.877	.001	.024	.053
Error	2359.995	48	49.167					

a. Computed using alpha = .05

PAH SRT 1 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	10.519	2	5.259	6.573	.002	.130	13.146	.901
	Greenhouse-Geisser	10.519	1.975	5.325	6.573	.002	.130	12.985	.898
	Huynh-Feldt	10.519	2.000	5.259	6.573	.002	.130	13.146	.901
	Lower-bound	10.519	1.000	10.519	6.573	.014	.130	6.573	.708
testtime * BLHA_grp	Sphericity Assumed	2.668	2	1.334	1.667	.195	.037	3.335	.343
	Greenhouse-Geisser	2.668	1.975	1.351	1.667	.195	.037	3.294	.341
	Huynh-Feldt	2.668	2.000	1.334	1.667	.195	.037	3.335	.343
	Lower-bound	2.668	1.000	2.668	1.667	.203	.037	1.667	.244
Error(testtime)	Sphericity Assumed	70.410	88	.800					
	Greenhouse-Geisser	70.410	86.922	.810					
	Huynh-Feldt	70.410	88.000	.800					
	Lower-bound	70.410	44.000	1.600					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2.988	1	2.988	1.216	.276	.027	1.216	.190
BLHA_grp	3.156	1	3.156	1.285	.263	.028	1.285	.198
Error	108.072	44	2.456					

a. Computed using alpha = .05

PAH SRT 1 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	14732.224	2	7366.112	6.614	.002	.123	13.229	.904
	Greenhouse-Geisser	14732.224	1.864	7904.674	6.614	.003	.123	12.327	.888
	Huynh-Feldt	14732.224	1.979	7444.411	6.614	.002	.123	13.089	.901
	Lower-bound	14732.224	1.000	14732.224	6.614	.013	.123	6.614	.712
testtime * BLHA_grp	Sphericity Assumed	2607.658	2	1303.829	1.171	.315	.024	2.342	.251
	Greenhouse-Geisser	2607.658	1.864	1399.157	1.171	.312	.024	2.182	.243
	Huynh-Feldt	2607.658	1.979	1317.688	1.171	.314	.024	2.317	.250
	Lower-bound	2607.658	1.000	2607.658	1.171	.285	.024	1.171	.185
Error(testtime)	Sphericity Assumed	104684.970	94	1113.670					
	Greenhouse-Geisser	104684.970	87.596	1195.094					
	Huynh-Feldt	104684.970	93.011	1125.508					
	Lower-bound	104684.970	47.000	2227.340					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	6974727.744	1	6974727.744	2535.284	.000	.982	2535.284	1.000
BLHA_grp	49.062	1	49.062	.018	.894	.000	.018	.052
Error	129299.990	47	2751.064					

a. Computed using alpha = .05

PAH Match to Sample (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	3.670	2	1.835	6.142	.003	.099	12.284	.882
	Greenhouse-Geisser	3.670	1.903	1.928	6.142	.003	.099	11.688	.870
	Huynh-Feldt	3.670	2.000	1.835	6.142	.003	.099	12.284	.882
	Lower-bound	3.670	1.000	3.670	6.142	.016	.099	6.142	.683
testtime * BLHA_grp	Sphericity Assumed	.525	2	.263	.880	.418	.015	1.759	.198
	Greenhouse-Geisser	.525	1.903	.276	.880	.413	.015	1.674	.194
	Huynh-Feldt	.525	2.000	.263	.880	.418	.015	1.759	.198
	Lower-bound	.525	1.000	.525	.880	.352	.015	.880	.152
Error(testtime)	Sphericity Assumed	33.456	112	.299					
	Greenhouse-Geisser	33.456	106.566	.314					
	Huynh-Feldt	33.456	112.000	.299					
	Lower-bound	33.456	56.000	.597					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	3.136	1	3.136	6.320	.015	.101	6.320	.695
BLHA_grp	1.294	1	1.294	2.608	.112	.045	2.608	.355
Error	27.786	56	.496					

a. Computed using alpha = .05

PAH Match to Sample (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	1574.641	2	787.321	6.675	.002	.120	13.351	.907
	Greenhouse-Geisser	1574.641	1.942	810.632	6.675	.002	.120	12.967	.900
	Huynh-Feldt	1574.641	2.000	787.321	6.675	.002	.120	13.351	.907
	Lower-bound	1574.641	1.000	1574.641	6.675	.013	.120	6.675	.717
testtime * BLHA_grp	Sphericity Assumed	499.570	2	249.785	2.118	.126	.041	4.236	.425
	Greenhouse-Geisser	499.570	1.942	257.180	2.118	.127	.041	4.114	.419
	Huynh-Feldt	499.570	2.000	249.785	2.118	.126	.041	4.236	.425
	Lower-bound	499.570	1.000	499.570	2.118	.152	.041	2.118	.297
Error(testtime)	Sphericity Assumed	11558.559	98	117.944					
	Greenhouse-Geisser	11558.559	95.182	121.437					
	Huynh-Feldt	11558.559	98.000	117.944					
	Lower-bound	11558.559	49.000	235.889					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	229170.792	1	229170.792	1065.562	.000	.956	1065.562	1.000
BLHA_grp	854.656	1	854.656	3.974	.052	.075	3.974	.498
Error	10538.448	49	215.070					

a. Computed using alpha = .05

PAH Math (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	34.365	2	17.182	25.057	.000	.309	50.113	1.000
	Greenhouse-Geisser	34.365	1.694	20.282	25.057	.000	.309	42.456	1.000
	Huynh-Feldt	34.365	1.773	19.384	25.057	.000	.309	44.421	1.000
	Lower-bound	34.365	1.000	34.365	25.057	.000	.309	25.057	.998
testtime * BLHA_grp	Sphericity Assumed	2.619	2	1.310	1.910	.153	.033	3.819	.389
	Greenhouse-Geisser	2.619	1.694	1.546	1.910	.160	.033	3.236	.356
	Huynh-Feldt	2.619	1.773	1.477	1.910	.158	.033	3.386	.365
	Lower-bound	2.619	1.000	2.619	1.910	.172	.033	1.910	.274
Error(testtime)	Sphericity Assumed	76.803	112	.686					
	Greenhouse-Geisser	76.803	94.886	.809					
	Huynh-Feldt	76.803	99.278	.774					
	Lower-bound	76.803	56.000	1.371					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	41.384	1	41.384	19.393	.000	.257	19.393	.991
BLHA_grp	1.749	1	1.749	.820	.369	.014	.820	.144
Error	119.501	56	2.134					

a. Computed using alpha = .05

PAH Math (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	1450.400	2	725.200	19.327	.000	.279	38.654	1.000
	Greenhouse-Geisser	1450.400	1.517	956.274	19.327	.000	.279	29.314	.999
	Huynh-Feldt	1450.400	1.585	914.800	19.327	.000	.279	30.643	.999
	Lower-bound	1450.400	1.000	1450.400	19.327	.000	.279	19.327	.991
testtime * BLHA_grp	Sphericity Assumed	138.594	2	69.297	1.847	.163	.036	3.694	.377
	Greenhouse-Geisser	138.594	1.517	91.377	1.847	.173	.036	2.801	.326
	Huynh-Feldt	138.594	1.585	87.414	1.847	.172	.036	2.928	.333
	Lower-bound	138.594	1.000	138.594	1.847	.180	.036	1.847	.266
Error(testtime)	Sphericity Assumed	3752.245	100	37.522					
	Greenhouse-Geisser	3752.245	75.836	49.478					
	Huynh-Feldt	3752.245	79.274	47.333					
	Lower-bound	3752.245	50.000	75.045					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	70130.067	1	70130.067	668.095	.000	.930	668.095	1.000
BLHA_grp	163.078	1	163.078	1.554	.218	.030	1.554	.231
Error	5248.512	50	104.970					

a. Computed using alpha = .05

PAH Sternberg (Z-Score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	11.472	2	5.736	5.454	.005	.087	10.908	.839
	Greenhouse-Geisser	11.472	1.992	5.760	5.454	.006	.087	10.863	.838
	Huynh-Feldt	11.472	2.000	5.736	5.454	.005	.087	10.908	.839
	Lower-bound	11.472	1.000	11.472	5.454	.023	.087	5.454	.632
testtime * BLHA_grp	Sphericity Assumed	4.062	2	2.031	1.931	.150	.033	3.862	.394
	Greenhouse-Geisser	4.062	1.992	2.040	1.931	.150	.033	3.847	.393
	Huynh-Feldt	4.062	2.000	2.031	1.931	.150	.033	3.862	.394
	Lower-bound	4.062	1.000	4.062	1.931	.170	.033	1.931	.277
Error(testtime)	Sphericity Assumed	119.897	114	1.052					
	Greenhouse-Geisser	119.897	113.530	1.056					
	Huynh-Feldt	119.897	114.000	1.052					
	Lower-bound	119.897	57.000	2.103					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	.006	1	.006	.002	.964	.000	.002	.050
BLHA_grp	7.119	1	7.119	2.702	.106	.045	2.702	.366
Error	150.169	57	2.635					

a. Computed using alpha = .05

PAH Sternberg (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	3314.999	2	1657.499	5.161	.007	.097	10.321	.816
	Greenhouse-Geisser	3314.999	1.998	1658.858	5.161	.007	.097	10.313	.815
	Huynh-Feldt	3314.999	2.000	1657.499	5.161	.007	.097	10.321	.816
	Lower-bound	3314.999	1.000	3314.999	5.161	.028	.097	5.161	.605
testtime * BLHA_grp	Sphericity Assumed	836.518	2	418.259	1.302	.277	.026	2.605	.276
	Greenhouse-Geisser	836.518	1.998	418.602	1.302	.277	.026	2.602	.276
	Huynh-Feldt	836.518	2.000	418.259	1.302	.277	.026	2.605	.276
	Lower-bound	836.518	1.000	836.518	1.302	.259	.026	1.302	.201
Error(testtime)	Sphericity Assumed	30833.107	96	321.178					
	Greenhouse-Geisser	30833.107	95.921	321.441					
	Huynh-Feldt	30833.107	96.000	321.178					
	Lower-bound	30833.107	48.000	642.356					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	780386.238	1	780386.238	980.650	.000	.953	980.650	1.000
BLHA_grp	1258.548	1	1258.548	1.582	.215	.032	1.582	.234
Error	38197.673	48	795.785					

a. Computed using alpha = .05

PAH SRT 2 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	10.729	2	5.364	8.556	.000	.166	17.112	.962
	Greenhouse-Geisser	10.729	1.574	6.817	8.556	.001	.166	13.465	.924
	Huynh-Feldt	10.729	1.661	6.458	8.556	.001	.166	14.213	.934
	Lower-bound	10.729	1.000	10.729	8.556	.005	.166	8.556	.816
testtime * BLHA_grp	Sphericity Assumed	.232	2	.116	.185	.831	.004	.370	.078
	Greenhouse-Geisser	.232	1.574	.148	.185	.779	.004	.291	.075
	Huynh-Feldt	.232	1.661	.140	.185	.791	.004	.308	.076
	Lower-bound	.232	1.000	.232	.185	.669	.004	.185	.071
Error(testtime)	Sphericity Assumed	53.919	86	.627					
	Greenhouse-Geisser	53.919	67.671	.797					
	Huynh-Feldt	53.919	71.432	.755					
	Lower-bound	53.919	43.000	1.254					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	7.164	1	7.164	2.511	.120	.055	2.511	.341
BLHA_grp	.974	1	.974	.341	.562	.008	.341	.088
Error	122.673	43	2.853					

a. Computed using alpha = .05

PAH SRT 2 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	22548.678	2	11274.339	13.090	.000	.229	26.179	.997
	Greenhouse-Geisser	22548.678	1.590	14178.428	13.090	.000	.229	20.817	.989
	Huynh-Feldt	22548.678	1.678	13439.197	13.090	.000	.229	21.962	.992
	Lower-bound	22548.678	1.000	22548.678	13.090	.001	.229	13.090	.943
testtime * BLHA_grp	Sphericity Assumed	3446.743	2	1723.372	2.001	.141	.043	4.002	.403
	Greenhouse-Geisser	3446.743	1.590	2167.284	2.001	.152	.043	3.182	.357
	Huynh-Feldt	3446.743	1.678	2054.287	2.001	.150	.043	3.357	.367
	Lower-bound	3446.743	1.000	3446.743	2.001	.164	.043	2.001	.283
Error(testtime)	Sphericity Assumed	75796.404	88	861.323					
	Greenhouse-Geisser	75796.404	69.975	1083.186					
	Huynh-Feldt	75796.404	73.824	1026.711					
	Lower-bound	75796.404	44.000	1722.646					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	6774634.355	1	6774634.355	2125.543	.000	.980	2125.543	1.000
BLHA_grp	16.030	1	16.030	.005	.944	.000	.005	.051
Error	140238.956	44	3187.249					

a. Computed using alpha = .05

PAH CPT 2 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	34.239	2	17.119	21.056	.000	.281	42.112	1.000
	Greenhouse-Geisser	34.239	1.817	18.846	21.056	.000	.281	38.254	1.000
	Huynh-Feldt	34.239	1.911	17.914	21.056	.000	.281	40.244	1.000
	Lower-bound	34.239	1.000	34.239	21.056	.000	.281	21.056	.995
testtime * BLHA_grp	Sphericity Assumed	1.968	2	.984	1.210	.302	.022	2.421	.260
	Greenhouse-Geisser	1.968	1.817	1.083	1.210	.300	.022	2.199	.248
	Huynh-Feldt	1.968	1.911	1.030	1.210	.301	.022	2.313	.254
	Lower-bound	1.968	1.000	1.968	1.210	.276	.022	1.210	.191
Error(testtime)	Sphericity Assumed	87.808	108	.813					
	Greenhouse-Geisser	87.808	98.104	.895					
	Huynh-Feldt	87.808	103.210	.851					
	Lower-bound	87.808	54.000	1.626					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	8.958	1	8.958	4.282	.043	.073	4.282	.529
BLHA_grp	3.285	1	3.285	1.570	.216	.028	1.570	.234
Error	112.983	54	2.092					

a. Computed using alpha = .05

PAH CPT 2 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	15219.118	2	7609.559	19.769	.000	.279	39.538	1.000
	Greenhouse-Geisser	15219.118	1.878	8105.473	19.769	.000	.279	37.119	1.000
	Huynh-Feldt	15219.118	1.985	7666.532	19.769	.000	.279	39.244	1.000
	Lower-bound	15219.118	1.000	15219.118	19.769	.000	.279	19.769	.992
testtime * BLHA_grp	Sphericity Assumed	811.960	2	405.980	1.055	.352	.020	2.109	.230
	Greenhouse-Geisser	811.960	1.878	432.438	1.055	.349	.020	1.980	.224
	Huynh-Feldt	811.960	1.985	409.020	1.055	.352	.020	2.094	.229
	Lower-bound	811.960	1.000	811.960	1.055	.309	.020	1.055	.172
Error(testtime)	Sphericity Assumed	39262.098	102	384.923					
	Greenhouse-Geisser	39262.098	95.759	410.008					
	Huynh-Feldt	39262.098	101.242	387.804					
	Lower-bound	39262.098	51.000	769.845					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1850824.999	1	1850824.999	1688.403	.000	.971	1688.403	1.000
BLHA_grp	1453.037	1	1453.037	1.326	.255	.025	1.326	.204
Error	55906.135	51	1096.199					

a. Computed using alpha = .05

PAH CPT 1 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	36.364	2	18.182	37.174	.000	.399	74.347	1.000
	Greenhouse-Geisser	36.364	1.838	19.779	37.174	.000	.399	68.344	1.000
	Huynh-Feldt	36.364	1.932	18.823	37.174	.000	.399	71.815	1.000
	Lower-bound	36.364	1.000	36.364	37.174	.000	.399	37.174	1.000
testtime * BLHA_grp	Sphericity Assumed	.947	2	.474	.969	.383	.017	1.937	.215
	Greenhouse-Geisser	.947	1.838	.515	.969	.377	.017	1.781	.207
	Huynh-Feldt	.947	1.932	.490	.969	.380	.017	1.871	.211
	Lower-bound	.947	1.000	.947	.969	.329	.017	.969	.162
Error(testtime)	Sphericity Assumed	54.780	112	.489					
	Greenhouse-Geisser	54.780	102.956	.532					
	Huynh-Feldt	54.780	108.185	.506					
	Lower-bound	54.780	56.000	.978					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	29.874	1	29.874	23.557	.000	.296	23.557	.998
BLHA_grp	2.307	1	2.307	1.819	.183	.031	1.819	.263
Error	71.017	56	1.268					

a. Computed using alpha = .05

PAH CPT 1 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	24682.131	2	12341.065	31.500	.000	.391	63.000	1.000
	Greenhouse-Geisser	24682.131	1.844	13385.409	31.500	.000	.391	58.085	1.000
	Huynh-Feldt	24682.131	1.952	12645.461	31.500	.000	.391	61.484	1.000
	Lower-bound	24682.131	1.000	24682.131	31.500	.000	.391	31.500	1.000
testtime * BLHA_grp	Sphericity Assumed	705.913	2	352.956	.901	.410	.018	1.802	.202
	Greenhouse-Geisser	705.913	1.844	382.825	.901	.403	.018	1.661	.195
	Huynh-Feldt	705.913	1.952	361.662	.901	.407	.018	1.758	.199
	Lower-bound	705.913	1.000	705.913	.901	.347	.018	.901	.154
Error(testtime)	Sphericity Assumed	38394.389	98	391.779					
	Greenhouse-Geisser	38394.389	90.354	424.933					
	Huynh-Feldt	38394.389	95.641	401.443					
	Lower-bound	38394.389	49.000	783.559					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1548326.379	1	1548326.379	1530.233	.000	.969	1530.233	1.000
BLHA_grp	1151.539	1	1151.539	1.138	.291	.023	1.138	.182
Error	49579.386	49	1011.824					

a. Computed using alpha = .05

PTH ANAM Com-Z

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	355.591	1	355.591	25.343	.000	.382	25.343	.998
	Greenhouse-Geisser	355.591	1.000	355.591	25.343	.000	.382	25.343	.998
	Huynh-Feldt	355.591	1.000	355.591	25.343	.000	.382	25.343	.998
	Lower-bound	355.591	1.000	355.591	25.343	.000	.382	25.343	.998
testtime * PTHgroups	Sphericity Assumed	139.644	2	69.822	4.976	.012	.195	9.953	.782
	Greenhouse-Geisser	139.644	2.000	69.822	4.976	.012	.195	9.953	.782
	Huynh-Feldt	139.644	2.000	69.822	4.976	.012	.195	9.953	.782
	Lower-bound	139.644	2.000	69.822	4.976	.012	.195	9.953	.782
Error(testtime)	Sphericity Assumed	575.270	41	14.031					
	Greenhouse-Geisser	575.270	41.000	14.031					
	Huynh-Feldt	575.270	41.000	14.031					
	Lower-bound	575.270	41.000	14.031					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	446.424	1	446.424	9.197	.004	.183	9.197	.842
PTHgroups	35.714	2	17.857	.368	.694	.018	.736	.105
Error	1990.221	41	48.542					

a. Computed using alpha = .05

PTH SRT 1 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	2.118	1	2.118	3.108	.086	.072	3.108	.405
	Greenhouse-Geisser	2.118	1.000	2.118	3.108	.086	.072	3.108	.405
	Huynh-Feldt	2.118	1.000	2.118	3.108	.086	.072	3.108	.405
	Lower-bound	2.118	1.000	2.118	3.108	.086	.072	3.108	.405
testtime * PTHgroups	Sphericity Assumed	5.058	2	2.529	3.711	.033	.157	7.422	.648
	Greenhouse-Geisser	5.058	2.000	2.529	3.711	.033	.157	7.422	.648
	Huynh-Feldt	5.058	2.000	2.529	3.711	.033	.157	7.422	.648
	Lower-bound	5.058	2.000	2.529	3.711	.033	.157	7.422	.648
Error(testtime)	Sphericity Assumed	27.260	40	.682					
	Greenhouse-Geisser	27.260	40.000	.682					
	Huynh-Feldt	27.260	40.000	.682					
	Lower-bound	27.260	40.000	.682					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2.199	1	2.199	.950	.335	.023	.950	.158
PTHgroups	.147	2	.073	.032	.969	.002	.063	.054
Error	92.560	40	2.314					

a. Computed using alpha = .05

PTH SRT 1 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	2629.379	1	2629.379	3.597	.065	.083	3.597	.457
	Greenhouse-Geisser	2629.379	1.000	2629.379	3.597	.065	.083	3.597	.457
	Huynh-Feldt	2629.379	1.000	2629.379	3.597	.065	.083	3.597	.457
	Lower-bound	2629.379	1.000	2629.379	3.597	.065	.083	3.597	.457
testtime * PTHgroups	Sphericity Assumed	4912.402	2	2456.201	3.360	.045	.144	6.721	.601
	Greenhouse-Geisser	4912.402	2.000	2456.201	3.360	.045	.144	6.721	.601
	Huynh-Feldt	4912.402	2.000	2456.201	3.360	.045	.144	6.721	.601
	Lower-bound	4912.402	2.000	2456.201	3.360	.045	.144	6.721	.601
Error(testtime)	Sphericity Assumed	29236.578	40	730.914					
	Greenhouse-Geisser	29236.578	40.000	730.914					
	Huynh-Feldt	29236.578	40.000	730.914					
	Lower-bound	29236.578	40.000	730.914					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	4014543.841	1	4014543.841	1600.321	.000	.976	1600.321	1.000
PTHgroups	144.109	2	72.054	.029	.972	.001	.057	.054
Error	100343.442	40	2508.586					

a. Computed using alpha = .05

PTH Sternberg (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	9.959	1	9.959	8.653	.005	.161	8.653	.821
	Greenhouse-Geisser	9.959	1.000	9.959	8.653	.005	.161	8.653	.821
	Huynh-Feldt	9.959	1.000	9.959	8.653	.005	.161	8.653	.821
	Lower-bound	9.959	1.000	9.959	8.653	.005	.161	8.653	.821
testtime * PTHgroups	Sphericity Assumed	3.807	2	1.904	1.654	.203	.068	3.308	.331
	Greenhouse-Geisser	3.807	2.000	1.904	1.654	.203	.068	3.308	.331
	Huynh-Feldt	3.807	2.000	1.904	1.654	.203	.068	3.308	.331
	Lower-bound	3.807	2.000	1.904	1.654	.203	.068	3.308	.331
Error(testtime)	Sphericity Assumed	51.790	45	1.151					
	Greenhouse-Geisser	51.790	45.000	1.151					
	Huynh-Feldt	51.790	45.000	1.151					
	Lower-bound	51.790	45.000	1.151					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	2.905	1	2.905	1.226	.274	.027	1.226	.192
PTHgroups	3.703	2	1.851	.781	.464	.034	1.563	.175
Error	106.620	45	2.369					

a. Computed using alpha = .05

PTH Sternberg (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	3216.864	1	3216.864	10.763	.002	.216	10.763	.892
	Greenhouse-Geisser	3216.864	1.000	3216.864	10.763	.002	.216	10.763	.892
	Huynh-Feldt	3216.864	1.000	3216.864	10.763	.002	.216	10.763	.892
	Lower-bound	3216.864	1.000	3216.864	10.763	.002	.216	10.763	.892
testtime * PTHgroups	Sphericity Assumed	2192.278	2	1096.139	3.667	.035	.158	7.335	.641
	Greenhouse-Geisser	2192.278	2.000	1096.139	3.667	.035	.158	7.335	.641
	Huynh-Feldt	2192.278	2.000	1096.139	3.667	.035	.158	7.335	.641
	Lower-bound	2192.278	2.000	1096.139	3.667	.035	.158	7.335	.641
Error(testtime)	Sphericity Assumed	11656.385	39	298.882					
	Greenhouse-Geisser	11656.385	39.000	298.882					
	Huynh-Feldt	11656.385	39.000	298.882					
	Lower-bound	11656.385	39.000	298.882					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	468103.132	1	468103.132	700.125	.000	.947	700.125	1.000
PTHgroups	1810.253	2	905.127	1.354	.270	.065	2.708	.274
Error	26075.357	39	668.599					

a. Computed using alpha = .05

PTH Match to Sample (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	.815	1	.815	3.998	.052	.082	3.998	.499
	Greenhouse-Geisser	.815	1.000	.815	3.998	.052	.082	3.998	.499
	Huynh-Feldt	.815	1.000	.815	3.998	.052	.082	3.998	.499
	Lower-bound	.815	1.000	.815	3.998	.052	.082	3.998	.499
testtime * PTHgroups	Sphericity Assumed	1.235	2	.618	3.029	.058	.119	6.058	.558
	Greenhouse-Geisser	1.235	2.000	.618	3.029	.058	.119	6.058	.558
	Huynh-Feldt	1.235	2.000	.618	3.029	.058	.119	6.058	.558
	Lower-bound	1.235	2.000	.618	3.029	.058	.119	6.058	.558
Error(testtime)	Sphericity Assumed	9.176	45	.204					
	Greenhouse-Geisser	9.176	45.000	.204					
	Huynh-Feldt	9.176	45.000	.204					
	Lower-bound	9.176	45.000	.204					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	.828	1	.828	1.682	.201	.036	1.682	.246
PTHgroups	.962	2	.481	.977	.384	.042	1.955	.209
Error	22.154	45	.492					

a. Computed using alpha = .05

PTH Match to Sample (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	339.138	1	339.138	3.844	.057	.084	3.844	.482
	Greenhouse-Geisser	339.138	1.000	339.138	3.844	.057	.084	3.844	.482
	Huynh-Feldt	339.138	1.000	339.138	3.844	.057	.084	3.844	.482
	Lower-bound	339.138	1.000	339.138	3.844	.057	.084	3.844	.482
testtime * PTHgroups	Sphericity Assumed	563.659	2	281.830	3.194	.051	.132	6.389	.580
	Greenhouse-Geisser	563.659	2.000	281.830	3.194	.051	.132	6.389	.580
	Huynh-Feldt	563.659	2.000	281.830	3.194	.051	.132	6.389	.580
	Lower-bound	563.659	2.000	281.830	3.194	.051	.132	6.389	.580
Error(testtime)	Sphericity Assumed	3705.527	42	88.227					
	Greenhouse-Geisser	3705.527	42.000	88.227					
	Huynh-Feldt	3705.527	42.000	88.227					
	Lower-bound	3705.527	42.000	88.227					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	128756.118	1	128756.118	617.525	.000	.936	617.525	1.000
PTHgroups	243.269	2	121.634	.583	.562	.027	1.167	.140
Error	8757.142	42	208.503					

a. Computed using alpha = .05

PTH Math (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	12.720	1	12.720	20.081	.000	.309	20.081	.992
	Greenhouse-Geisser	12.720	1.000	12.720	20.081	.000	.309	20.081	.992
	Huynh-Feldt	12.720	1.000	12.720	20.081	.000	.309	20.081	.992
	Lower-bound	12.720	1.000	12.720	20.081	.000	.309	20.081	.992
testtime * PTHgroups	Sphericity Assumed	.891	2	.446	.703	.500	.030	1.407	.161
	Greenhouse-Geisser	.891	2.000	.446	.703	.500	.030	1.407	.161
	Huynh-Feldt	.891	2.000	.446	.703	.500	.030	1.407	.161
	Lower-bound	.891	2.000	.446	.703	.500	.030	1.407	.161
Error(testtime)	Sphericity Assumed	28.503	45	.633					
	Greenhouse-Geisser	28.503	45.000	.633					
	Huynh-Feldt	28.503	45.000	.633					
	Lower-bound	28.503	45.000	.633					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	67.448	1	67.448	27.081	.000	.376	27.081	.999
PTHgroups	1.482	2	.741	.298	.744	.013	.595	.094
Error	112.076	45	2.491					

a. Computed using alpha = .05

PTH Math (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	627.142	1	627.142	18.198	.000	.302	18.198	.986
	Greenhouse-Geisser	627.142	1.000	627.142	18.198	.000	.302	18.198	.986
	Huynh-Feldt	627.142	1.000	627.142	18.198	.000	.302	18.198	.986
	Lower-bound	627.142	1.000	627.142	18.198	.000	.302	18.198	.986
testtime * PTHgroups	Sphericity Assumed	63.968	2	31.984	.928	.403	.042	1.856	.200
	Greenhouse-Geisser	63.968	2.000	31.984	.928	.403	.042	1.856	.200
	Huynh-Feldt	63.968	2.000	31.984	.928	.403	.042	1.856	.200
	Lower-bound	63.968	2.000	31.984	.928	.403	.042	1.856	.200
Error(testtime)	Sphericity Assumed	1447.396	42	34.462					
	Greenhouse-Geisser	1447.396	42.000	34.462					
	Huynh-Feldt	1447.396	42.000	34.462					
	Lower-bound	1447.396	42.000	34.462					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	50139.313	1	50139.313	375.303	.000	.899	375.303	1.000
PTHgroups	50.273	2	25.136	.188	.829	.009	.376	.077
Error	5611.068	42	133.597					

a. Computed using alpha = .05

PTH SRT 2 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	2.842	1	2.842	4.533	.041	.118	4.533	.543
	Greenhouse-Geisser	2.842	1.000	2.842	4.533	.041	.118	4.533	.543
	Huynh-Feldt	2.842	1.000	2.842	4.533	.041	.118	4.533	.543
	Lower-bound	2.842	1.000	2.842	4.533	.041	.118	4.533	.543
testtime * PTHgroups	Sphericity Assumed	.990	2	.495	.789	.462	.044	1.578	.173
	Greenhouse-Geisser	.990	2.000	.495	.789	.462	.044	1.578	.173
	Huynh-Feldt	.990	2.000	.495	.789	.462	.044	1.578	.173
	Lower-bound	.990	2.000	.495	.789	.462	.044	1.578	.173
Error(testtime)	Sphericity Assumed	21.317	34	.627					
	Greenhouse-Geisser	21.317	34.000	.627					
	Huynh-Feldt	21.317	34.000	.627					
	Lower-bound	21.317	34.000	.627					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	.017	1	.017	.006	.941	.000	.006	.051
PTHgroups	1.528	2	.764	.255	.777	.015	.509	.087
Error	102.028	34	3.001					

a. Computed using alpha = .05

PTH SRT 2 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	4051.245	1	4051.245	5.599	.023	.128	5.599	.635
	Greenhouse-Geisser	4051.245	1.000	4051.245	5.599	.023	.128	5.599	.635
	Huynh-Feldt	4051.245	1.000	4051.245	5.599	.023	.128	5.599	.635
	Lower-bound	4051.245	1.000	4051.245	5.599	.023	.128	5.599	.635
testtime * PTHgroups	Sphericity Assumed	8763.274	2	4381.637	6.056	.005	.242	12.112	.859
	Greenhouse-Geisser	8763.274	2.000	4381.637	6.056	.005	.242	12.112	.859
	Huynh-Feldt	8763.274	2.000	4381.637	6.056	.005	.242	12.112	.859
	Lower-bound	8763.274	2.000	4381.637	6.056	.005	.242	12.112	.859
Error(testtime)	Sphericity Assumed	27494.405	38	723.537					
	Greenhouse-Geisser	27494.405	38.000	723.537					
	Huynh-Feldt	27494.405	38.000	723.537					
	Lower-bound	27494.405	38.000	723.537					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	4011005.665	1	4011005.665	1362.335	.000	.973	1362.335	1.000
PTHgroups	481.172	2	240.586	.082	.922	.004	.163	.062
Error	111880.130	38	2944.214					

a. Computed using alpha = .05

PTH CPT 1 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	14.236	1	14.236	29.808	.000	.398	29.808	1.000
	Greenhouse-Geisser	14.236	1.000	14.236	29.808	.000	.398	29.808	1.000
	Huynh-Feldt	14.236	1.000	14.236	29.808	.000	.398	29.808	1.000
	Lower-bound	14.236	1.000	14.236	29.808	.000	.398	29.808	1.000
testtime * PTHgroups	Sphericity Assumed	4.211	2	2.106	4.409	.018	.164	8.818	.731
	Greenhouse-Geisser	4.211	2.000	2.106	4.409	.018	.164	8.818	.731
	Huynh-Feldt	4.211	2.000	2.106	4.409	.018	.164	8.818	.731
	Lower-bound	4.211	2.000	2.106	4.409	.018	.164	8.818	.731
Error(testtime)	Sphericity Assumed	21.492	45	.478					
	Greenhouse-Geisser	21.492	45.000	.478					
	Huynh-Feldt	21.492	45.000	.478					
	Lower-bound	21.492	45.000	.478					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	42.171	1	42.171	43.174	.000	.490	43.174	1.000
PTHgroups	.141	2	.070	.072	.931	.003	.144	.060
Error	43.954	45	.977					

a. Computed using alpha = .05

PTH CPT 1 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	9496.717	1	9496.717	23.109	.000	.360	23.109	.997
	Greenhouse-Geisser	9496.717	1.000	9496.717	23.109	.000	.360	23.109	.997
	Huynh-Feldt	9496.717	1.000	9496.717	23.109	.000	.360	23.109	.997
	Lower-bound	9496.717	1.000	9496.717	23.109	.000	.360	23.109	.997
testtime * PTHgroups	Sphericity Assumed	3198.286	2	1599.143	3.891	.028	.160	7.783	.671
	Greenhouse-Geisser	3198.286	2.000	1599.143	3.891	.028	.160	7.783	.671
	Huynh-Feldt	3198.286	2.000	1599.143	3.891	.028	.160	7.783	.671
	Lower-bound	3198.286	2.000	1599.143	3.891	.028	.160	7.783	.671
Error(testtime)	Sphericity Assumed	16849.306	41	410.959					
	Greenhouse-Geisser	16849.306	41.000	410.959					
	Huynh-Feldt	16849.306	41.000	410.959					
	Lower-bound	16849.306	41.000	410.959					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	978841.521	1	978841.521	1319.957	.000	.970	1319.957	1.000
PTHgroups	479.802	2	239.901	.324	.725	.016	.647	.098
Error	30404.391	41	741.571					

a. Computed using alpha = .05

PTH CPT 2 (Z-score)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	18.824	1	18.824	30.103	.000	.406	30.103	1.000
	Greenhouse-Geisser	18.824	1.000	18.824	30.103	.000	.406	30.103	1.000
	Huynh-Feldt	18.824	1.000	18.824	30.103	.000	.406	30.103	1.000
	Lower-bound	18.824	1.000	18.824	30.103	.000	.406	30.103	1.000
testtime * PTHgroups	Sphericity Assumed	5.260	2	2.630	4.206	.021	.160	8.411	.709
	Greenhouse-Geisser	5.260	2.000	2.630	4.206	.021	.160	8.411	.709
	Huynh-Feldt	5.260	2.000	2.630	4.206	.021	.160	8.411	.709
	Lower-bound	5.260	2.000	2.630	4.206	.021	.160	8.411	.709
Error(testtime)	Sphericity Assumed	27.514	44	.625					
	Greenhouse-Geisser	27.514	44.000	.625					
	Huynh-Feldt	27.514	44.000	.625					
	Lower-bound	27.514	44.000	.625					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	11.832	1	11.832	6.917	.012	.136	6.917	.730
PTHgroups	.887	2	.444	.259	.773	.012	.519	.088
Error	75.267	44	1.711					

a. Computed using alpha = .05

PTH CPT 2 (T-put)

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
testtime	Sphericity Assumed	8311.349	1	8311.349	27.752	.000	.398	27.752	.999
	Greenhouse-Geisser	8311.349	1.000	8311.349	27.752	.000	.398	27.752	.999
	Huynh-Feldt	8311.349	1.000	8311.349	27.752	.000	.398	27.752	.999
	Lower-bound	8311.349	1.000	8311.349	27.752	.000	.398	27.752	.999
testtime * PTHgroups	Sphericity Assumed	2779.026	2	1389.513	4.640	.015	.181	9.279	.752
	Greenhouse-Geisser	2779.026	2.000	1389.513	4.640	.015	.181	9.279	.752
	Huynh-Feldt	2779.026	2.000	1389.513	4.640	.015	.181	9.279	.752
	Lower-bound	2779.026	2.000	1389.513	4.640	.015	.181	9.279	.752
Error(testtime)	Sphericity Assumed	12578.575	42	299.490					
	Greenhouse-Geisser	12578.575	42.000	299.490					
	Huynh-Feldt	12578.575	42.000	299.490					
	Lower-bound	12578.575	42.000	299.490					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	1055271.114	1	1055271.114	1273.390	.000	.968	1273.390	1.000
PTHgroups	462.548	2	231.274	.279	.758	.013	.558	.091
Error	34805.830	42	828.710					

a. Computed using alpha = .05

PAH Bess Total Score

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
DAY	Sphericity Assumed	802.523	3	267.508	15.993	.000	.162	47.979	1.000
	Greenhouse-Geisser	802.523	2.586	310.282	15.993	.000	.162	41.365	1.000
	Huynh-Feldt	802.523	2.709	296.235	15.993	.000	.162	43.327	1.000
	Lower-bound	802.523	1.000	802.523	15.993	.000	.162	15.993	.977
DAY * BLHAGRP	Sphericity Assumed	10.135	3	3.378	.202	.895	.002	.606	.088
	Greenhouse-Geisser	10.135	2.586	3.919	.202	.869	.002	.522	.085
	Huynh-Feldt	10.135	2.709	3.741	.202	.877	.002	.547	.086
	Lower-bound	10.135	1.000	10.135	.202	.654	.002	.202	.073
Error(DAY)	Sphericity Assumed	4164.871	249	16.726					
	Greenhouse-Geisser	4164.871	214.674	19.401					
	Huynh-Feldt	4164.871	224.854	18.523					
	Lower-bound	4164.871	83.000	50.179					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	38039.826	1	38039.826	428.197	.000	.838	428.197	1.000
BLHAGRP	2.661	1	2.661	.030	.863	.000	.030	.053
Error	7373.486	83	88.837					

a. Computed using alpha = .05

PAH SAC Total Score

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
DAY	Sphericity Assumed	39.966	3	13.322	5.179	.002	.055	15.538	.923
	Greenhouse-Geisser	39.966	2.663	15.010	5.179	.003	.055	13.790	.897
	Huynh-Feldt	39.966	2.783	14.360	5.179	.002	.055	14.415	.907
	Lower-bound	39.966	1.000	39.966	5.179	.025	.055	5.179	.615
DAY * BLHAGRP	Sphericity Assumed	25.076	3	8.359	3.250	.022	.035	9.749	.742
	Greenhouse-Geisser	25.076	2.663	9.418	3.250	.027	.035	8.652	.704
	Huynh-Feldt	25.076	2.783	9.010	3.250	.025	.035	9.044	.718
	Lower-bound	25.076	1.000	25.076	3.250	.075	.035	3.250	.430
Error(DAY)	Sphericity Assumed	686.760	267	2.572					
	Greenhouse-Geisser	686.760	236.968	2.898					
	Huynh-Feldt	686.760	247.703	2.773					
	Lower-bound	686.760	89.000	7.716					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1

Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	219791.545	1	219791.545	25104.465	.000	.996	25104.465	1.000
BLHAGRP	2.479	1	2.479	.283	.596	.003	.283	.082
Error	779.202	89	8.755					

a. Computed using alpha = .05

PTH SAC Total Score

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
DAY	Sphericity Assumed	46.068	2	23.034	8.465	.000	.086	16.930	.963
	Greenhouse-Geisser	46.068	1.793	25.687	8.465	.001	.086	15.181	.949
	Huynh-Feldt	46.068	1.868	24.659	8.465	.000	.086	15.814	.955
	Lower-bound	46.068	1.000	46.068	8.465	.005	.086	8.465	.821
DAY * PTHGRP	Sphericity Assumed	7.323	4	1.831	.673	.612	.015	2.691	.216
	Greenhouse-Geisser	7.323	3.587	2.042	.673	.596	.015	2.413	.205
	Huynh-Feldt	7.323	3.736	1.960	.673	.602	.015	2.514	.209
	Lower-bound	7.323	2.000	3.661	.673	.513	.015	1.346	.160
Error(DAY)	Sphericity Assumed	489.810	180	2.721					
	Greenhouse-Geisser	489.810	161.408	3.035					
	Huynh-Feldt	489.810	168.139	2.913					
	Lower-bound	489.810	90.000	5.442					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	176855.021	1	176855.021	21528.384	.000	.996	21528.384	1.000
PTHGRP	11.929	2	5.964	.726	.487	.016	1.452	.169
Error	739.347	90	8.215					

a. Computed using alpha = .05

PTH BESS Total Score

Tests of Within-Subjects Effects

Measure: MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
DAY	Sphericity Assumed	624.160	2	312.080	22.123	.000	.208	44.246	1.000
	Greenhouse-Geisser	624.160	1.704	366.297	22.123	.000	.208	37.697	1.000
	Huynh-Feldt	624.160	1.777	351.230	22.123	.000	.208	39.314	1.000
	Lower-bound	624.160	1.000	624.160	22.123	.000	.208	22.123	.996
DAY * PTHGRP	Sphericity Assumed	77.289	4	19.322	1.370	.247	.032	5.479	.421
	Greenhouse-Geisser	77.289	3.408	22.679	1.370	.252	.032	4.668	.384
	Huynh-Feldt	77.289	3.554	21.746	1.370	.251	.032	4.868	.393
	Lower-bound	77.289	2.000	38.645	1.370	.260	.032	2.739	.287
Error(DAY)	Sphericity Assumed	2369.898	168	14.107					
	Greenhouse-Geisser	2369.898	143.134	16.557					
	Huynh-Feldt	2369.898	149.274	15.876					
	Lower-bound	2369.898	84.000	28.213					

a. Computed using alpha = .05

Tests of Between-Subjects Effects

Measure: MEASURE_1
Transformed Variable: Average

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
Intercept	26197.041	1	26197.041	318.724	.000	.791	318.724	1.000
PTHGRP	509.686	2	254.843	3.101	.050	.069	6.201	.583
Error	6904.252	84	82.193					

a. Computed using alpha = .05

Appendix F Manuscript

The Effects of Headache on Clinical Measures of Neuropsychological Function and Postural Stability

Context: Headache is a common condition in both the athletic and non-athletic population as well as the most common post-concussive symptom. As headache can affect activities of daily living, it may also affect clinical measures commonly used to assess neuropsychological performance and postural stability.

Objective: To determine the effects of preseason assessment headache and post-traumatic headache on measures of neuropsychological function and postural stability

Design: Subjects performed serial testing on measures of neuropsychological performance and postural stability with a repeated measures design.

Intervention: Pre-Season Assessment Headache and Posttraumatic Headache

Main Outcome Measures: A Graded Symptom Checklist (GSC) was used to assess symptom severity and presence. The Automated Neuropscholgical Assessment Metrics (ANAM) and Standardized Assessment of Concussion were used to assess neuropsychological function and mental status. The Balance Error Scoring System (BESS) was used to assess postural stability. A concussion history questionnaire was used to assess previous history of concussion.

Results: Investigation of the effects of PAH revealed a significant main effect of day ($p<.05$) and interaction effect ($P<.05$) regarding symptom total score and total number of symptoms endorsed. A significant interaction effect ($p<.05$) was also found for the SAC. A main effect of day ($p<.05$) was found for all measures of ANAM. For PTH a significant interaction effect ($p<.05$) and a main effect of day ($p<.05$) was found for symptom total score and total number of symptoms endorsed. A significant interaction effect was found for ANAM Composite-Z, SRT 1 Z-score and throughput score, CPT 1 Z-score and throughput score, CPT 2 Z-score and throughput score, Sternberg throughput score, and SRT 2 throughput score. A significant main effect of day ($p<.05$) was found for all ANAM measures with the exception of SRT 1 and Match to Sample.

Conclusions: Clinicians should be mindful of the presence of headache both pre and post-injury as pre-injury, it may affect the presence of other symptoms as well as other aspects of neurocognition and post-injury it may affect both symptoms and neuropsychological performance.

Key Words: Headache, balance, concussion, cognition

INTRODUCTION

Concussion is a common injury occurring in sport, as there are approximately 300,000 reported sports-related head injuries each year in the US. (Thurman, Branche, & Sniezek, 1998) Management of head injury and return to play (RTP) for athletes have become debated topics in the healthcare community due to variability of management strategies and RTP guidelines. Although there is debate, most health care providers agree that assessment and management of concussion involves thorough and repeated evaluations. Concussion may result in a cluster of symptoms ranging from mild headache to loss of consciousness (LOC). Headache (HA) is one of the hallmark symptoms of concussion and occurs in up to 86% of concussed individuals. Many times, LOC and post-traumatic amnesia (PTA) are used as indicators of concussion; however, LOC occurs in only 9% of cases and PTA occurs in only 23%. (Guskiewicz, Weaver, Padua, & Garrett, 2000) Despite being the most common concussive symptom, post-traumatic headache (PTH) is often over looked or dismissed as a minor symptom. Although common, there is a limited understanding about the relevance of this symptom specifically related to RTP. Current literature suggests a relationship between neuropsychological test scores, prevalence of symptoms, and PTH presence and severity. Collins et al 2003, reported reduction in neuropsychological test performance and increased symptoms in individuals suffering from PTH through 10 days post-injury. These individuals also demonstrated more on-field markers of concussion severity than individuals who did not suffer from PTH.(Collins et al., 2003) The presence of post-traumatic migraine (PTM) characteristics and PTH are also closely related to other symptoms and neuropsychological test scores. Individuals suffering from PTH with PTM characteristics suffer greater neurocognitive deficits compared to a PTH group without those features and when compared to a non-HA group. Individuals reporting PTH also performed significantly worse on neuropsychological tests and reported an increased number of symptoms post injury compared to individuals reporting no-HA. (Mihalik et al., 2005) These studies indicate important effects of PTH on clinical measures of concussion; however, the presence and effects of pre-injury HA but are some of the first to examine HA in this special population. The presence and effects of pre-injury HA whether episodic or chronic, are other factors needing investigation. Due to limited research, there is an incomplete understanding of the effects of both PTH and pre-injury HA on measures of postural stability and neuropsychological performance. Many factors may play a role regarding these effects, including type of HA, number of previous concussions, severity of previous concussions, location/severity of impact, and severity of current injury. Literature provides evidence that all of these factors play a role in the manifestation and duration of symptoms. (Guskiewicz et al., 2003) reported that 30% of individuals suffering from 3 or more concussions reported symptoms lasting greater than one week compared to 14.6% of individuals with history of only one previous concussion. One of the few studies involving HA and concussion reported increased incidence of symptoms as well as severity in individuals with a higher PTH score. (Collins et al., 2003) Although literature suggests a relationship between number of previous concussions, symptom presence and other clinical measures, the role of HA in this relationship is poorly understood.

Clinical outcome measures provide clinicians with valuable information regarding an injured individual's recovery. The presence of certain symptoms is one of the most common clinical signs that there is disruption in normal brain function. With headache being the most common of these symptoms, its effects on clinical measures is important to clinicians in management and RTP decisions. Therefore, the purpose of this study was to examine the effects of PTH and pre-injury assessment HA on clinical measures of concussion as measured by the Automated Neuropsychological Assessment Metric (ANAM), the Balance Error Scoring System (BESS), the Standard Assessment of Concussion (SAC), and a graded symptom check list (GSC). Our second purpose was to examine the association between both pre-injury assessment HA and PTH with frequency of previous concussion.

METHODS

Subjects

Subjects were recruited for this study on the basis of involvement in basketball, football, lacrosse, and soccer at randomly selected high schools across the east coast. Subjects were of both high school and collegiate athletes (age = 16.65 ± 1.87 years) recruited from 110 high schools and 14 colleges. Males to female ratio was 301 to 74.

Testing Protocol

This study used data gathered from 110 high schools and 14 colleges on 247 concussed individuals. All of these individuals completed baseline testing and serial testing on days one, three, and seven post-injury on the GSC, SAC and the BESS. Subjects complete ANAM testing at a sub-acute testing date (day 1-2 post-injury) and a prolonged testing date (day 5-7 post-injury). All subjects completed a GSC and concussion history questionnaire. A subset of 100 of the subjects completed the BESS and the SAC at all test dates. Another subset of 45 of these subjects completed ANAM testing during the acute and the prolonged testing sessions. In relation to pre-season assessment HA the subjects were grouped by those with a positive baseline headache score (PHA), and those with a negative baseline headache score (NHA). Score regarding PTH, subject data were stratified by those with no PTH score day one post-injury, those with a mild PTH score (1-2) day one post-injury, and those with a moderate to severe PTH score (3-6) day one postinjury.

Instrumentation

Graded Symptom Checklist

The graded symptom checklist (GSC) is a 7 pt Likert scale grading system that allows individuals to self- report and rate a variety of concussive symptoms. Current literature suggests this to be a commonly used practical measure of symptomology regarding concussion. We used a 20 item checklist in this study.

Automated Neuropsychological Assessment Metrics

For the purposes of this study, the Automated Neuropsychological Assessment Metrics (ANAM) was used in assessing neuropsychological function. We used five testing modules (simple reaction time, continuous performance test, math processing, Sternberg memory, and match to sample) Simple reaction time (SRT), assesses reaction time. The continuous performance test (CPT) assesses concentration and working memory. Math processing (MTH) assesses mental processing speed and mental efficiency. The Sternberg (STN) memory measures working memory and match to sample (MTS) measures visual memory. We will test on all five of these modules, during each testing session with a second SRT and CPT module being completed . (Bleiberg et al., 2004; Bleiberg, Halpern, Reeves, & Daniel, 1998) We then calculated the overall composite Z-score for the entire battery and the individual throughput scores for each of the seven individual modules. These scores were also compared at the sub-acute and prolonged testing sessions.

Standardized Assessment of Concussion

The SAC was used to assess mental status. This instrument assesses orientation by asking five general orientation questions; immediate memory by assessing recall of five words; delayed recall by assessing recall of the five words from immediate memory at the end of the test, and concentration bye asking the subject to repeat a string of numbers in reverse order. It has been proven to be both sensitive and specific in detecting mental status deficits and has been used as a valid and reliable instrument across all levels of sport.(McCrea, 2001a, 2001b; McCrea, Kelly, & Randolph, 2000; McCrea, Kelly, Randolph, Cisler, & Berger, 2002)

Balance Error Scoring System

Postural stability testing gives clinicians an important piece of information regarding management and RTP of sports-related concussion. There are a variety of options available to assess postural stability. For the purpose of this study, the BESS was used. The BESS has been proven to be both a reliable and valid measure of postural stability. (Riemann BL, 2000; Riemann, Guskiewicz, & Shields, 1999) We used six twenty second trails on three different stances (double leg, single leg, tandem) on two different surfaces (firm, foam). Individuals were asked to perform the single leg balance task on the non-dominant foot. Dominance was defined by which leg would be used to kick a ball. (Riemann BL, 2000; Riemann, Guskiewicz, & Shields, 1999) Errors were recorded if the individual lifted hands off of their iliac crest, abducted or flexed their hip to greater than thirty degrees, stepped, stumbled or fell, opened eyes, or remained out of the testing position for greater than five seconds. A higher score indicates a greater deficit in postural stability.

Data Analyses

Data analyses were conducted using SPSS 13.0 (Chicago, IL). Scores on BESS, SAC, and the GSC in the retrospective design investigating the effects of PAH were analyzed using 2x4 repeated measures, mixed model ANOVAs. Scores investigating the effects of PTH on these same measures were analyzed using 3x3 repeated measures mixed model ANOVAs. Regarding the effects of PAH on ANAM, 2x2 repeated measures mixed model ANOVAs were used. Lastly scores for the effects of PTH on ANAM, 3x2 repeated measures mixed model ANOVAs were used. In these analyses, the between subjects factor was the HA group and the within subjects factor was the test day. When comparing previous history of concussion between the two groups regarding PAH, and between the three PTH groups, two Cross tabs/Chi Square analyses were used.

RESULTS

The purpose of this study was to examine the effects of headache on clinical measures of postural stability and neuropsychological performance. This was accomplished by grouping subjects based on a reported headache score at baseline for the first portion of the study and by grouping subjects based on their headache at day 1 post-injury for the second portion of the study. These individuals were tested on four basic clinical measures at serial testing dates.

We examined the association between pre-season assessment headache (PAH) and history of previous concussions. A Chi Square test of association suggested an association between these two factors ($\chi 2 = 14.48$, df = 3, $p = .002$). A Crosstabs analysis suggested that individuals who reported three or more previous concussions are more likely to report HA at baseline (Table 1). We also examined the association between posttraumatic headache (PTH) and history of previous concussion using a Chi Square test of association and Crosstabs. No significant association was observed.

We also examined the effects of PAH on the graded symptom checklist (GSC), the Standardized Assessment of Concussion (SAC), and the Balance Error Scoring System (BESS). A repeated measures ANOVA revealed no significant effects on the BESS. A significant interaction effect ($F_{3,267}$=3.25, p=.027) and a main effect of day ($F_{3,267}$=5.18, p=.002) was observed for the SAC. A significant interaction effect was also observed for symptom total score ($F_{3,675}$= 3.41, p=.03) and total number of symptoms endorsed ($F^{3,675}$=5.63, p=.024). A main effect of day was observed for symptom total score ($F_{1,225}$=77.75, p<.005) (Figure 1) and total number of symptoms endorsed ($F_{3,675}$=108.94, p<.005) (Table 2).

Investigation of the effects of PAH on neuropsychological performance using repeated measures ANOVAs revealed no significant interactions for any portion of ANAM. A main effect of day was observed for all modules (p<.05).

We then examined the effects of PTH on a GSC, the SAC, and the BESS. A repeated measures ANOVA revealed no significant findings pertaining to the SAC or the BESS. However, significant interaction effects as well as a main effect of day was observed for symptom total score ($F_{4,458}$ = 24.98, p<.005) (Figure 2) and total number of symptoms endorsed ($F_{4,458}$ = 20.88, p<.005) (Table 3).

Our final question investigated effects of PTH on neuropsychological performance. A repeated measures ANOVA revealed no significant interactions for the Z-scores of Simple Reaction time 2, Math Processing, Match to Sample, Sternberg memory or SRT 2. Significant interactions were found for the Z-scores of Composite Score ($F_{2,41}$=4.98, p=0.01)

(Figure 3), Simple Reaction Time 1 ($F_{2,40}$ = 3.71, p=.03), Continuous Performance Test 1 ($F_{2,45}$ = 4.41, p=.02), and Continuous Performance Test 2 ($F_{2,44}$=4.21, p=.02). A main effect of day (p<.05) was observed for all Z-score modules with the exception of Match to Sample, and Simple Reaction Time 1 (Table 4). Significant interactions were also found for the throughput scores of Simple Reaction Time 1 ($F_{2,40}$=3.36, p=.46), Continuous Performance Test 1 ($F_{2,41}$=3.89, p=.028), Sternberg Memory Search ($F_{2,39}$=3.67, p=.035), Simple Reaction Time 2 ($F_{2,38}$=6.06, p=.005), and Continuous Performance Test 2 ($F_{2,42}$=4.64, p=.015). A main effect of day (p<.05) was observed for all throughput measures except Match to Sample (Table 4).

DISCUSSION

Although studies have examined common clinical measures of concussion, few have examined the effects of HA on these measures. Current studies suggest HA may affect an individual's ability to perform normally on neurocognitive tasks which lead to the primary purposes of our study. One specific goal of the study was to examine the effects of headache, both PAH and PTH on clinical measures of neuropsychological performance and postural stability. Our second aim was to examine the association of concussion and HA. Current literature discusses the effects of PTH and PTM on measures similar to those used in our study. These studies display increase in symptoms as well as deficits in neuropsychological test scores in individuals reporting PTH at day 1 post-injury.(Collins et al., 2003; Mihalik et al., 2005) Our findings were consistent with those of Collins and Mihalik et al.

Pre-Season Assessment Headache

The first portion of our study examined the effects of PAH (HA reported at baseline) on symptoms, ANAM, the SAC, the BESS, and a GSC. To our knowledge no other study has examined the effects of headache in healthy athletes on clinical measures of concussion. As our study may be one of the first, it suggests that individuals presenting with headache upon baseline testing may display an increase in other symptoms as well as an increase in the intensity of these symptoms. This is important to clinicians as they should note if the athlete presented with a headache at baseline as this may affect the overall symptom total score. The SAC yielded a significant group x day interaction leading to the suggestion that the effect of the test score on a given day depended upon the HA classification of the athlete. In regards to neuropsychological testing, there were no significant differences found between the groups or any group by day interactions suggesting that headache at baseline may have little effect on this type of neuropsychological testing battery. A main effect of day was found regarding all modules of ANAM using both the Z-scores and the throughput scores. This is consent with literature as deficits appear post-injury and begin to resolve as time elapses. As a result of practice effects, individuals often improve on the tests by day seven. Another important finding of this portion of the study was the significant association of previous history of concussion and HA reported at baseline. Individuals suffering from three are more concussions were more likely to report HA at baseline than individuals with a history of less than three. This finding is consistent with current literature suggesting that after three or more concussions long term repercussions may be present. (Guskiewicz et al., 2003) The association also provides further information as to why individuals experiencing headache at baseline display an increase in symptoms as well as a slower symptomatic recovery.

Posttraumatic Headache

The second portion of our study investigated these same measures regarding PTH. We found that individuals reporting PTH reported an increased number of symptoms and a greater intensity of symptoms than individuals not reporting HA. This finding was magnified in individuals reporting moderate-severe PTH suggesting that HA severity may indicate other levels of neurocognitive deficits. We also found that both the Z-scores and throughput scores of CPT 1 and CPT 2 , SRT 1 and SRT 2 displayed significant interactions. The STN and SRT 2 throughput scores also yielded significant interactions. These results suggest that the increased neurocognitive deficits seen in these individuals were a result of the combination of both the headache and the concussive injury.

Headache, Concussion, and Pain

Current literature suggests pain, including headache effects concentration, mental processing, and reaction time. Our study reinforces thesis findings as PTH significantly affected mental processing (CPT 1 and 2) as well the reaction time measures (SRT 1 and 2). This finding reinforces current literature suggesting that PTH is a sign of incomplete recovery and other neurocognitive deficits. (Collins et al., 2003) As headache often precedes many other postconcussive symptoms, the neurocognitive and other aspects of postconcussion syndrome, may be at least in part the result of the headache. (Hooker, 1986) Studies have found evidence of neuropsychological impairment in cases of PTH; however, there are no published studies which help to explain the potential sources of these impairments. Many confounding factors ranging from pain, the actual brain injury or other causes may contribute to neuropsycholgical impairment. (Nicholson, Martelli, & Zasler, 2001) In our study, we found significant interactions between PTH and neurospycholgical measures with no main effect of HA group, and no significant interactions for these measures regarding PAH suggesting differences may be a combination of the HA and the concussion. Headache, concussion, and general pain may alter cerebral blood flow as well as affect depolarization of neurons, alter excitatory amino acids, nitric oxide, neuropeptides, glucose, magnesium/calcium, and neurotransmitters such as nonepinephrine and serotonin. (Gilkey, Ramadan, Aurora, & Welch, 1997; Packard RC, 1997; Takahashi, Manaka, & Sano, 1981).

Limitations

Although our study yielded important clinical findings, it did present with some limitations. The number of males in our study greatly outnumbered the females which may have lead to skewed data, especially in relation to HA as females are more likely to experience HA. We also only used information out to day 7 post-injury. Although many concussions have resolved by this point, many to do not completely resolve until day 10 post-injury or beyond. Various athletic trainers also conducted the testing at different testing sites, which may have lead to variability in testing procedures and timing. We believe the greatest limitation to our study was the small subset of individuals who completed the ANAM testing battery at all dates included in the study. This lead to a small sample size, decreased power, and unbalanced group design that may have been a hindrance to statistical significance. Although these limitations were present we believe our study provides valuable clinical information regarding HA and clinical measures of concussion.

Clinical Implication

Headache is common in the physically active population indicating the need for a more clear understanding of its effects on commonly used clinical measures of concussion. Our study suggests that individuals suffering from HA at baseline as well as individuals reporting HA at day 1 post-injury display an increased number of symptoms and an increase in intensity of symptoms throughout all test times reinforcing current literature emphasizing the importance of asymptomatic return to play. Concerning PTH and symptoms, our findings reiterate current literature suggesting HA as sign of incomplete recovery. Our study only looked out to post-injury day 7 and previous literature has only looked out to day 10. Future research should investigate these effects further from time of injury as well as the effects of headache in a healthy physically active population. These studies should include both asymptomatic (no HA) and symptomatic (HA) test sessions to truly isolate the effects of HA on these clinical measures. Lastly, our study reinforces the findings of (McCrea et al., 2005) implicating that neuropsychological testing should be used as a more sensitive measure after complete symptom resolution, as an athlete would not return if symptomatic regardless of neuropsychological test scores. If the athlete is asymptomatic, the neuropsychological test results would provide clinicians with more valuable information.

CONCLUSIONS

As clinicians, we should be mindful of the presence of HA in both our healthy and unhealthy athletes as HA may affect many aspects of neurocognition. We should be especially mindful of HA in concussed athletes as it is a sign of incomplete recovery and possible other neurological deficits.

Table 1. Number of Previous Concussions per Group (last 7 years)

	0	1	2	3+
NHG	69.0%	23.0%	7.8%	.3%
(n = 258)	177	60	20	1
PHG	59.5%	24.5%	9.4%	6.6%
(n=106)	63	26	10	7

$\chi^2 = 14.48$ df = 3   p = .002

NHG- negative headache group
PHG- positive headache

Percentages (%) are expressed as a proportion of subjects of each group

Table 2. Pre-Season Assessment Headache Clinical Measures Scores Means and Standard Deviations

	Baseline	**Day 1 post-injury**	**Day 3 post-injury**	**Day 7 post -injury**	**Group Main Effect**	**Group X Day Interaction**	**Day Main Effect**
Symptom Total							
No PAH	1.62 (3.47)	10.99 (12.98)	5.55 (10.37)	1.96 (6.48)	$F_{1,225} = 3.175$	$F_{3,675} = 3.414$	$F_{3,675} = 77.75$
+ PAH	5.65 (6.41)	13.56 (13.13)	6.46 (9.92)	1.60 (4.56)	$p = .076$	$p = .033$	$p < .005$
	2.74 (4.82)	11.70 (13.04)	5.80 (10.23)	1.86 (5.99)			
Symptoms Endorsed							
No PAH	0.91 (1.59)	4.80 (4.11)	2.77 (3.95)	0.92 (2.39)	$F_{1,83} = 5.57$	$F_{3,675} = 5.63$	$F_{3,675} = 108.94$
+PAH	2.86 (2.84)	5.76 (3.99)	3.28 (3.56)	0.83 (1.83)	$p = .019$	$p = .024$	$p < .005$
	1.45 (2.12)	5.07 (4.09)	2.92 (3.85)	0.89 (2.24)			
SAC Total Score							
No PAH	26.85 (1.64)	26.62 (2.79)	27.62 (1.72)	26.08 (1.74)	$F_{1,89} = .283$	$F_{3, 267} = 3.250$	$F_{3, 267} = 5.18$
+PAH	27.35 (1.85)	26.88 (1.79)	26.73 (2.66)	27.46 (1.66)	$p = .596$	$p = .027$	$p = .002$
	26.99 (1.71)	26.69 (2.54)	27.36 (2.59)	27.90 (1.73)			
BESS Total Score	11.85 (4.76)	14.23 (7.11)	11.13 (6.65)	9.60 (5.66)	$F_{1,83} = .030$	$F_{3,249} = .202$	$F_{3,249} = 15.99$
No PAH	11.20 (4.27)	14.08 (7.27)	11.52 (4.58)	9.24 (4.86)	$p = .863$	$p = .869$	$p < .005$
+PAH							
	11.66 (4.60)	14.19 (7.12)	11.25 (6.02)	9.50 (5.42)			

Table 3. Posttraumatic Headache Clinical Measures Scores Means and Standard Deviations

	Day 1 post-injury	Day 3 post-injury	Day 7 post - injury	Group Main Effect	Group X Day Interaction	Day Main Effect
Symptom Total			.			
No PTH	2.32 (3.42)	1.19 (3.94)	43 (2.21)	$F_{2,229} = 29.75$	$F_{4,458} = 4.98$	$F_{2,458} = 00.21$
Mild PTH	8.07 (8.27)	3.35 (5.43)	.81 (2.06)	$p < .005$	$p < .005$	$p < .005$
Mod-Severe PTH	19.16 (15.23)	10.02 (13.43)	3.32 (8.35)			
	11.88 (13.31)	5.90 (10.40)	1.86 (5.94)			
Symptoms Endorsed						
No PTH	1.53 (2.12)	0.66 (1.76)	0.21 (0.93)	$F_{1,83} = 5.57$	$F_{4,458} = 20.878$	$F_{2,458} = 62.96$
Mild PTH	4.31 (3.41)	2.25 (2.83)	0.58 (1.46)	$p = .019$	$p < .005$	$p < .005$
Mod-Severe PTH	7.28 (3.98)	4.51 (4.58)	1.42 (2.90)			
	5.08 (4.11)	2.94 (3.89)	.88 (2.22)			
SAC Total Score						
No PTH	27.50 (1.75)	27.56 (1.37)	28.25 (1.57)	$F_{2,89} = .283$	$F_{4, 180} = .673$	$F_{2, 180} = 8.46$
Mild PTH	26.44 (2.99)	27.22 (1.72)	27.94 (1.97)	$p = .596$	$p = .596$	$p = .001$
Mod-Severe PTH	26.63 (2.32)	27.46 (2.50)	27.63 (1.58)			
	26.71 (2.53)	27.39 (2.04)	27.86 (1.73)			
BESS Total Score						
No PTH	10.71 (5.23)	9.86 (4.47)	8.86 (3.37)	$F_{2,84} = .030$	$F_{4,168} = 1.37$	$F_{2,168} = 2.12$
Mild PTH	13.31 (6.15)	10.03 (3.40)	8.06 (5.54)	$p = .05$	$p = .252$	$p < .005$
Mod-Severe PTH	16.02 (7.76)	12.41 (7.27)	10.66 (5.62)			
	14.17 (7.04)	11.13 (6.01)	9.41 (5.38)			

Table 4. Posttraumatic Headache ANAM Composite Z-Score and Throughput Scores Means and Standard Deviations

	Sub-acute post-injury	Prolonged post-injury	Group Main Effect	Group X Day Interaction	Day Main Effect
Composite Z					
No PTH	1.60 (5.69)	4.74 (6.33)	$F_{1,41}$ = .368	$F_{2,41}$= 4.98	$F_{1,41}$ = 25.343
Mild PTH	1.39 (5.24)	3.44 (5.49)	p = .694	p = .012	p <.005
Mod-Severe PTH	-2.23 (6.93)	5.25 (4.80)			
	-0.05 (5.93)	*4.45 (5.34)*			
SRT 1					
No PTH	241.43 (47.59)	235.94 (51.85)	$F_{1,40}$= .029	$F_{2,40}$= 3.36	$F_{1,40}$= 3.59
Mild PTH	233.99 (47.46)	243.14 (26.95)	p = .969	p = .045	p = .065
Mod-Severe PTH	224.63 (39.70)	257.75 (36.49)			
	230.63 (43.20)	*249.10 (36.60)*			
CPT 1					
No PTH	112.36 (27.65)	130.31 (16.15)	$F_{1,41}$ = .324	$F_{2,41}$= 3.89	$F_{1,41}$ = 23.11
Mild PTH	109.46 (19.19)	122.43 (17.75)	p = .725	p = .028	p <.005
Mod-Severe PTH	95.39 (28.87)	133.78 (26.63)			
	103.21 (29.09)	*129.10 (22.44)*			
Math					
No PTH	24.48 (5.86)	27.35 (7.95)	$F_{1,42}$ = .188	$F_{2,42}$= .928	$F_{1,42}$= 18.19
Mild PTH	22.82 (7.87)	29.61 (17.09)	p = .829	p = .403	p <.005
Mod-Severe PTH	20.88 (4.64)	28.39 (5.63)			
	22.21 (6.19)	*28.64 (11.17)*			
Match to Sample					
No PTH	41.83 (8.81)	42.76 (11.67)	$F_{1,42}$= .583	$F_{2,42=}$ 3.19	$F_{1,42}$= 3.84
Mild PTH	41.54 (10.18)	42.36 (14.12)	p = .562	p = .051	p = .057
Mod-Severe PTH	33.34 (10.21)	44.22 (14.71)			
	37.77 (10.61)	*43.30 (13.74)*			
Sternberg					
No PTH	77.46 (15.54)	99.65 (41.89)	$F_{1,39}$= 1.35	$F_{2,39}$ = 3.67	$F_{1,39}$ = 10.76
Mild PTH	82.47 (15.73)	81.52 (20.19)	p = .270	p = .035	p = .002
Mod-Severe PTH	66.09 (23.94)	85.71 (17.29)			
	73.84 (21.08)	*86.54 (23.95)*			
SRT 2					
No PTH	239.99 (43.41)	236.60 (41.29)	F_{138} = .082	F_{238}= 6.06	$F_{1,38}$ = 5.60
Mild PTH	230.42 (38.81)	235.01 (37.70)	p = .922	p = .005	p = .023
Mod-Severe PTH	210.10 (55.65)	253..57 (35.05)			
	223.86 (48.08)	*243.02 (37.37)*			
CPT 2					
No PTH	111.85 (26.55)	130.29 (19.87)	$F_{1,42}$= .259	$F_{2,42}$= 4.64	$F_{1,42}$= 27.75
Mild PTH	111.46 (22.16)	121.72 (22.72)	p = .758	p = .015	p < .005
Mod-Severe PTH	97.64 (27.96)	131.86 (21.13)			
	105.08 (26.16)	*127.83 (21.59)*			

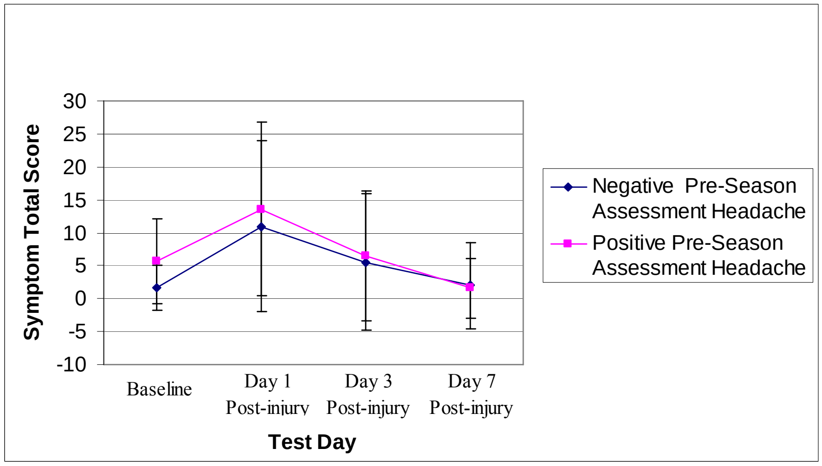

Figure 1. PAH Symptom Total Score

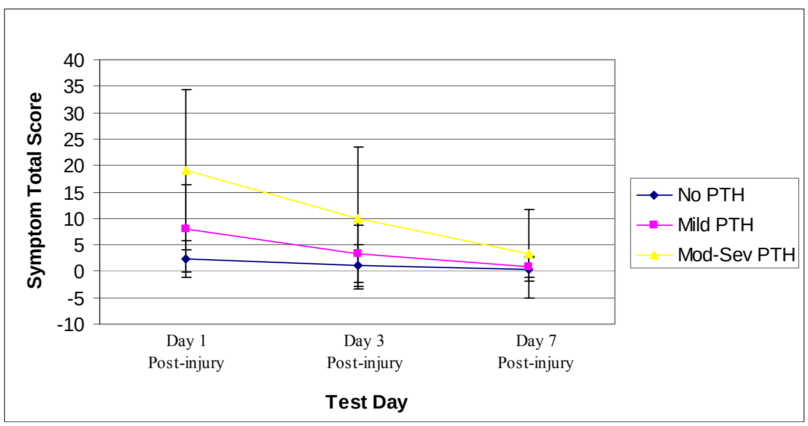

Figure 2. PTH Symptom Total Score

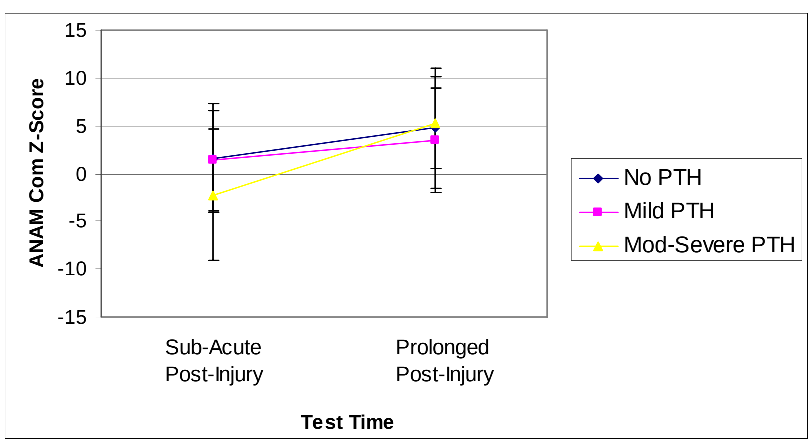

Figure 3. PTH ANAM Composite Z-Score

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